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Economic analysis of alternatives for railroad vegetation control

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ECONOMIC ANALYSIS OF ALTERNATIVES FOR

RAILROAD VEGETATION CONTROL

A

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RAILROAD VEGETATION CONTROL

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ABSTRACT

A survey was distributed to 174 railroads throughout the United States and selected foreign countries. The purpose of the survey was to determine which methods of vegetation control were used along railroad rights-of-way. Cost data were gathered from the railroads responding to the survey and the data were analyzed and compared to an independent cost analysis. Vegetation control by herbicide application, brush cutting, ballast regulating, reballasting, undercutting, and hand clearing were examined. The least expensive alternatives (in average U.S. data base, 1991 dollar base) were vegetation control with a ballast regulator at a cost of $330 per mile, herbicide application at $485 per mile, and brush cutting with a cost of $554 per mile. An integrated vegetation management program should be developed using a combination of these methods to get the most effective and economic vegetation control.

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LIST OF ABBREVIATIONS

ADEC - Alaska Department of Environmental Conservation
AREA - American Railway Engineering Association
ADOT & PF - Alaska Department of Transportation and Public Facilities
ARRC - Alaska Railroad Corporation
BN - Burlington Northern Railroad
CDA - controlled droplet applicator
CN - Canadian National Railway
DNOC - dinitrophenol
EPA - Environmental Protection Agency
IPM - integrated pest management
IVM - integrated vegetation management

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CHAPTER 1

INTRODUCTION

The project presented in this thesis encompasses a study of integrated vegetation management techniques for railroad rights-of-way that focuses on railroads outside the state of Alaska. It contains descriptions and economic analyses of techniques to control vegetation, including chemical, physical, and other methods. Data for the cost analyses were obtained by a survey of railroads throughout the United States and foreign countries. A list of the railroads surveyed is included as Appendix C, and the details of the survey are discussed in Chapters 4 and 5. The data base for the cost study was supplemented by literature references.

OBJECTIVES AND JUSTIFICATION

The objective of this project is to compare different methods of vegetation control on railroad rights-of-way and establish which of the alternatives comprises the least cost option for a specified level of control. The research was done for the Alaska Railroad Corporation (ARRC) in response to their request for a pesticide application permit. Public opposition to proposed herbicide usage along ARRC right-of-way resulted in a study of alternative vegetation control methods to be used in place of or in conjunction with herbicides. Social and political pressures exist which support the use of integrated vegetation management (IVM), which is discussed extensively in Chapter 2. IVM has the additional advantage of optimizing the objectives of a vegetation control program. This thesis will not specifically address the ARRC and their use of the data presented; rather it evaluates vegetation control techniques for railroads in general.

PROJECT HISTORY

The ARRC applied to the Alaska Department of Environmental Conservation (ADEC) for a permit to use herbicides on their right-of-way in January of 1988. The permit was denied by ADEC because of a directive issued by Governor Hammond on May 11, 1978 to the ADEC and the State of Alaska Department of Transportation and Public Facilities (ADOT & PF). The directive halted the widespread application of herbicides until data on herbicide persistence under cold Alaskan conditions were gathered. Subsequent governors, Sheffield and Cowper, upheld the Hammond directive.

The railroad had applied to use the herbicides Garlon 3A, manufactured by DOW Chemical Company, and Velpar, manufactured by E.I DuPont Corporation. The ARRC contracted with the University of Alaska Fairbanks (UAF) to field test the two herbicides and to study their persistence and migration (Mulkey, 1990). Also included in the testing program was a series of controlled lab experiments (Owen, 1990). To supplement the herbicide research program, a study on IVM techniques was commissioned. This study contained three parts: (1) evaluation the ARRC's vegetation management program (Preston, 1990); (2) investigation into methods other railroads are using to control vegetation on their rights-of-way (this volume); and (3) field experimentation along the Alaska Railroad to assess the effectiveness of seven vegetation control methods over the course of two growing seasons (Tilsworth, et al., 1991).

CHAPTER 2

VEGETATION CONTROL MANAGEMENT

This chapter contains a discussion of the importance of vegetation control along railroad rights-of-way. Areas that experience unique vegetation control problems that will be elaborated upon are the track ballast area, the shoulders and ditches, the structures along the railway, and the railway yards. The concept of integrated vegetation management (IVM) will be explored in this chapter along with the types of unwanted vegetation that trouble railroads.

NEED FOR VEGETATION CONTROL

The primary purpose in eliminating unwanted vegetation is to insure the safety of passengers, crew and goods. According to the Federal Railroad Administration's Track Safety Standards, vegetation along the track or in the track structure, which consists of the railroad ties and the area between the ties, must be controlled. Vegetation must not present a fire hazard, obstruct visibility, interfere with normal employee duties, prevent proper functioning of railroad signal and communication lines, or prevent visual inspections of moving equipment (Archdeacon and Ellsworth, 1985; Federal Government, 1988; Swan, et al., 1988; Anonymous, 1989).

Vegetation should also be controlled to keep water from accumulating and maintain good drainage in the track structure. Adequate vegetation control also facilitates maintenance of bridges, buildings and structures and helps provide a safe walkway along the track. When vegetation control is inadequate the sight distance around curves and at crossings may become obstructed and objects can be hidden from view by vegetation growth, increasing the possibility of an accident (Hoover, 1986). Shrubs and tall grasses must be controlled in areas of close proximity to the track for good visibility when grassland is part of the railroad right-of-way (Lacey, 1985).

The American Railway Engineering Association (AREA) lists a number of diverse areas in which vegetation should be controlled. They are the ballast; shoulders and ditches; around bridges, buildings and other structures; in railroad yards; around signal appurtenances and wayside signs; and under signal, communication and power lines (AREA, 1988).

Some states have laws that require railroads to control noxious weeds in their right-of-way. A noxious weed is one that is considered sufficiently harmful to the environment, cropland, or waterway to make its control essential. One hundred thirty-seven plant species have been declared by state law as noxious weeds in the continental United States (Anderson, 1983). The railroads must keep the noxious weeds from spreading onto pasture or cropland adjacent to the railroad right-of-way in such cases (Anonymous, 1987a).

IMPORTANCE OF ADEQUATE DRAINAGE

Vegetation promotes poor drainage in the ballast area which consists of the railroad ties, the area between the ties, and the side slopes of the track structure. Increased moisture in the ballast may cause an uplift of the ties when heavy loads travel over the track. This uplift produces a suction effect or "pumping" of soft fine soils into the ballast (Hay, 1982; Moehren, 1983). Uneven settling and heaving of the track may occur during freeze-thaw cycles because of moisture and fine soil particles present in the ballast. This can lead to accelerated wear on the track. For safety reasons, train speeds may have to be lowered in these areas, reducing the amount of traffic and resulting in potential loss of revenues. Settling also breaks up the track structure and causes uneven track wear and instability which can lead to accidents (Hay, 1982).

Ballast without fine soil grains can more readily form an interlocking structure that supports the tie and the track geometry. The tighter the interlocking of the ballast particles, the longer the track structure will remain intact. When fine particles invade the ballast, they serve to wear it down and to act as a lubricant such that proper compaction of the ballast and a tight interlocking of the particles is impeded (Moehren, 1983).

Recent studies by Selig (in Chrismer, 1988) suggest that the ballast particles do not experience an intrusion of fine particles from below, but rather the ballast itself breaks down. The addition of water in this situation increases the likelihood that the ballast particles will abrade and thus create more fine particles. "Pumping" of ballast has been cited as the symptom rather than the cause of ballast failure because it indicates that the ballast is in its final stages of breakdown (Chrismer, 1988).

Ballast may be fouled by subgrade intrusion ("pumping"), internal abrasion of ballast particles, or by external intrusion of fine particles carried into the ballast. Internal and external intrusion have been cited as the most common method of ballast fouling, but all three mechanisms work simultaneously to foul the ballast (Hay, 1982). By deferring right-of-way maintenance, railroads have found that uncontrolled vegetation growth greatly expedites deterioration of all structural components of the system (the subgrade, ballast, ties, hardware, and adjacent drainage ditches) that are essential to successful operation (Archdeacon and Ellsworth, 1985; Anonymous, 1985c, Anonymous, 1989).

INTEGRATED VEGETATION MANAGEMENT

Integrated pest management (IPM) is a new term in the vegetation control community. IPM is a system of management for all types of pests. Integrated vegetation management (IVM) is a more specific kind of IPM which refers to the control of unwanted vegetation. The term IVM is used in a variety of contexts and is associated with a number of different concepts. Generally, IVM is the practice of making use of all feasible control methods to obtain the most practical, effective, and economic results for vegetation control in order to form a program that optimizes vegetation control for the system (Anonymous, 1980; Caswell, et al., 1981-1982). Another aspect of IVM is that the vegetation population is kept to a level below that which causes economic injury (Matthews, 1984; Hatfield and Thomason, 1982). Establishing this level may be a difficult procedure for railroads.

Some distinction has been made between political use of IPM and real IPM. In political usage, IPM implies the complete elimination of chemical control methods and embraces only non-chemical methods. Real IPM combines technology and nature's methods in order to control vegetation (Hatfield and Thomason, 1982; Hill, 1982). The focus of this thesis is on methods that effectively control vegetation but which do not rely solely on the use of chemical means and are based on an understanding of the vegetation control program in the full environmental context (Watterson, 1988).

Unwanted Vegetation

The average yearly state roadside vegetation budget for U.S. transportation agencies in 1986 was seven million dollars (Johnson, 1988). Railroads also spend large sums of money to control vegetation that invades their rights-of-way. The average maintenance of way and structures budget for railroads from a survey of a large number of United States railroads was three thousandths of a dollar (1982) per gross ton-mile of rail travel (Tennyson, 1983). From the right-of-way and structures budget, monies for the vegetation control program are allocated; commonly monies for vegetation control compete directly with monies for track maintenance and upgrading procedures. Track maintenance and vegetation control may enhance each other because some track maintenance procedures provide vegetation control, and additionally adequate vegetation control facilitates efficient track maintenance. This relationship between maintenance and vegetation control produces cost sharing benefits which are discussed further in Chapter 6.

One important aspect of a vegetation control program is to establish what constitutes a weed so that an appropriate control plan can be devised. A species of plant that normally is not considered a weed may be a pest in some circumstance and thus a weed. (Archdeacon and Ellsworth, 1985). Weeds are plants which grow in the wrong place, in the wrong quantity, or at the wrong time (Lacey, 1985) and interfere with man's activities or his welfare (Anonymous, 1989).

Types of Vegetation

A variety of vegetation grows along railroad rights-of-way consisting of both woody and herbaceous plants. Depending on the geographical location, some of these may be classified as noxious weeds. One of the toughest noxious weeds to eradicate is Johnsongrass, a perennial that has shoots two to six feet high with ten to twenty foot long underground root structures called rhizomes (Anonymous, 1984c).

Woody plants are perennials that have hard stems composed mainly of wood tissue, while herbaceous plants (herbs) are soft stemmed (Viereck and Little, 1972; Swan, et al., 1988). Grasses have one single seedleaf and their mature leaves have parallel veins. Broadleaf plants have two seedleaves, and their mature leaves are generally broad with net-like patterned veins. Grasses are herbaceous, but broadleaf species may have woody or herbaceous stems (Cole, et al., 1987).

Each of these plant growth forms presents unique vegetation control problems. Another way to categorize vegetation is by the length of time it takes to complete a life cycle. There are three classifications: annuals, biennials, and perennials.

Annuals

Annuals grow from seeds, complete a life cycle in one growing season and can be classified as summer or winter annuals depending on when they germinate. Summer annuals germinate in the spring and die by winter while winter annuals usually germinate in the late summer or fall and die by the summer (Stewart, 1986; Cole, et al., 1987). Annuals produce an abundance of seeds that germinate during the subsequent growing seasons. To effectively control annuals the plants need to be destroyed before they have a chance to produce seed (Archdeacon and Ellsworth, 1985; Swan, et al, 1988), preferably in the seedling stage of growth (Stewart, 1986).

Biennials

Biennials generally require two growing seasons to complete their reproductive cycle. This type of plant also reproduces by seeds, and the most effective way to control them is to eliminate the plants, before they are well established, in their first year of growth (Swan, et al, 1988). Common examples of biennials are wild carrot and teasel (Cole, et al., 1987).

Perennials

Plants that grow back yearly are referred to as perennials. They can develop extensive root systems in addition to producing seeds. New plants are sometimes produced from the root system. For herbaceous species, the above ground component of the plant dies each fall, and in the spring new shoots are produced by the root system. They are the most costly type of plant to control as the underground root system must frequently be destroyed to prevent reproduction (Archdeacon and Ellsworth, 1985; Swan, et al., 1988). Perennials may reproduce by seed, crown buds, and cut root systems or they may spread by underground root and creeping above ground systems. Examples of herbaceous perennials are dandelion, wild barley, Canada thistle, toadflax, and leafy spurge (Stewart, 1986).

Most control methods of perennials are more effective when adapted to the growth cycle of the specific species. Plants are most susceptible in the fast growth period prior to flowering or during regrowth following fruiting or cutting (Stewart, 1986; Cole, et al., 1987; Swan, et al., 1988). Annuals present the biggest vegetation control problem in most of the contiguous United States. Perennials are the most prevalent species of plant life in Alaska, where there is a relatively short growing season and harsh winters (Johnson, 1990).

Extent of Vegetation Control

The degree and frequency of vegetation control are factors that need to be established for a vegetation control program. The amount of vegetation control chosen usually depends on economic factors, but is also influenced by engineering concerns. Some methods of vegetation management inherently contain a fixed measure of control, while others vary the amount of control. For example, with chemical control applications the dosage of herbicide used can be varied to obtain different degrees of control, while in mechanical brush cutting procedures the amount of control is fixed as the shrubs are cut to the same level each time. The most expensive degree of control is to completely remove all vegetation so that only bare ground remains (AREA, 1988). The other extreme is to not control any vegetation; this is also an expensive alternative when the cost of the damage to the track structure, and the decrease in traffic efficiency is considered. The majority of vegetation control programs for the track structure fall between the two extremes, and aim for short term control of most plant species.

Evaluation of Vegetation Infestation

Railroads should develop a specific plan to evaluate the extent of vegetation infestation that appears in their rights-of-way. In the 1970's Burlington Northern (BN) developed a numerical ranking system to describe the degree of vegetation growth in a particular area of their roadbed (Anonymous, 1973a). On the same date each year BN evaluates their right-of-way. They use a numbered ranking system from one to ten where one represents an area with zero to ten percent coverage by vegetation, two represents an area ten to twenty percent covered with vegetation, etc. A vegetation ranking number is determined for a stretch of track and the number of miles that contain this vegetation ranking are recorded. Next, the number of miles are multiplied by the vegetation ranking number to establish the number of points for an area. To find an average scoring of a certain number of miles, the points for each section in the area are added together and then divided by the total number of miles. The scores are then mapped for easy reference and the areas with the greatest vegetation control problems (highest point values) are easily distinguished

(Anonymous, 1973a). This is just one example of a ranking system used in a vegetation control program to establish the amount of vegetation cover. It is essential that railroads devise similar types of evaluation techniques specifically suited to their needs so adequate vegetation control and monitoring programs are developed.

DEVELOPING A VEGETATION CONTROL PROGRAM

In conjunction with monitoring vegetation levels along rights-of-way, a five step approach has been developed as a guideline in establishing a total vegetation control program (Smith, 1987). The first step is to monitor the vegetation levels present. This may be accomplished through a ranking system as discussed in the preceding section or by another suitable method. Next, the railroad determines the vegetation infestation level that causes damage. The third step involves the establishment of an action level so that injurious vegetation levels, as defined in step two, are not reached. Treatment methods then should be chosen to combat different types of vegetation infestation. Finally, a program to evaluate the results should be established to provide feedback to the vegetation control program (Smith, 1987).

DESCRIPTION OF VEGETATION CONTROL AREAS

It is necessary to understand railroad track structure geometry when discussing vegetation control because the method of control and the types of acceptable vegetation differ within the right-of-way areas. Figure 1 is a pictorial representation of a railroad right-of-way. The total railroad right-of-way may be up to 200 feet or more in width. The track roadbed is contained within this right-of-way and consists of subbase (subgrade material) and ballast material that, along with the crossties, serves to structurally support the rail. The subgrade is usually formed by compacting and shaping existing material at the construction site. The ballast section is built on top of this subgrade and consists of crushed or angular rock that meets railroad specification on strength, particle size, purity, and other factors. At the base of the subgrade fill is a ditch to allow water to drain away from the ballast. The area from the edge of this ditch to the boundary of the right-of-way is referred to as the wider right-of-way, as this area does not provide direct structural support for the track. The track roadbed is defined as the area from ditch to ditch and includes the ballast and shoulders of the subgrade. The area between the crossties is included in the roadbed unless otherwise specified.

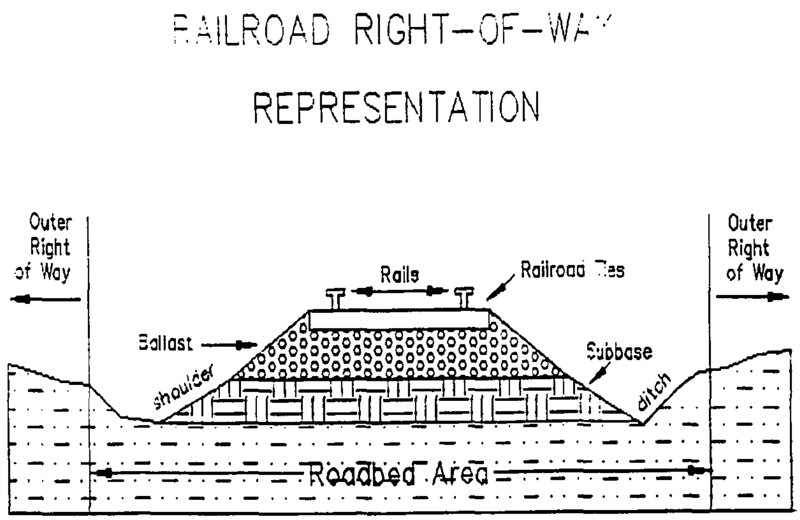


Figure 1: Railroad Right-of-Way Representation

NON-RAILROAD VEGETATION CONTROL

There are many other organizations and groups that have established vegetation control programs in addition to railroad systems. One of the most common is farmers who control unwanted species of vegetation in their fields or pastures. The goal for their vegetation control programs differs from that of railroads because farmers aim to remove specific plant species while railroads ideally would like to remove all plant species within the ballast area. At times when railroads are concerned with the removal of noxious weeds in the rights-of-way, their vegetation control programs parallel that of farmers.

Boroughs, counties, states and other political subdivisions also establish vegetation control programs for their rights-of-way along highways, roads, and freeways. Their primary focus is to provide adequate sight distance for curves, signs, and intersections. Ground cover in the form of low growing vegetative species is acceptable in their rights-of-way. In the outer right-of-way, railroads have similar vegetation control goals, primarily to provide adequate sight distance.

Utility companies control vegetation that grows under their power and communication lines; railroads may have vegetation control programs that match those needs of the utility companies because trees and shrubs must also be kept to an acceptable height under their power and communication lines. This is important because vegetation can interfere with wires and cause breakage during storms (Hay, 1982). Dams and other flood control projects control vegetation to maintain the integrity of their structures, and to reduce the amount of moisture that is held in the system. Railroad vegetation control programs aimed at the roadbed area have similar objectives in eliminating all plant species.

CHAPTER 3

LITERATURE REVIEW:

METHODS OF VEGETATION CONTROL

A wide variety of techniques have been and are in use to eliminate undesirable vegetation. Methods employed are influenced by many factors including growing season, climate, species of plant present, available resources, political pressures, and economics. Vegetation control techniques can be categorized into chemical, physical, and other methods. The following chapter contains a detailed discussion of each of these methods.

CHEMICAL

One form of vegetation control is the use of chemicals (herbicides) to reduce or eliminate unwanted vegetation.

History of Herbicides

In recent years vegetation management programs on railroad rights-of-way have been dominated by chemical weed control methods (Archdeacon and Ellsworth, 1985). Herbicides have a long history of use beginning with crop and pasture applications. As far back as 470 BC olive oil was used by Democrates as a pesticide on plants to prevent blight. Sulfur fumes were used in 200 BC to protect vines from fungi. Wine, which acted as a fungicide, was added to cereal seed to prevent mildew from forming in 23 AD (Watterson, 1988). The first chemical that was noted to behave as a selective herbicide, a compound that damages one species and leaves others intact, was copper sulfate. In 1897 a French vinegrower, Bonnet, found that copper sulfate would kill charlock (Sinapis arvensis) without affecting grasses (Ware, 1978; Lever, 1982). Modern herbicides started to appear in the 1930's, and from the period of 1906 to 1960 sodium arsenite solutions were the standard herbicides used (Ware, 1978). In 1933, denitrophenol (DNOC), the first herbicide for weed control in cereals was patented in France (Lacey, 1985).

Herbicide Usage

There has been an exponential growth in the number of patents for herbicides in the past thirty years. From 1950 to 1980 the number increased from 50 to 4,700 patents issued yearly in the United States (Lacey, 1985). The number of products on the market and the total value of the agricultural chemical business rose from $755 million to $9.7 billion between 1950 and 1979 (Lever, 1982). By 1986 pesticides had developed approximately a $13 billion dollar world-wide market (Watterson, 1988).

In 1976 one hundred chemically different herbicides were commercially available around the world, and 450 officially approved formulations were applied annually on 10.5 to 13.5 million acres of agricultural land in the United Kingdom (Lacey, 1985). Approximately 1,200 pesticide compounds consisting of 30,000 formulations and brands were in use in the United States by 1981. This translates into 900 million pounds of pesticide active ingredients applied per year, which is 35 to 45 percent of the world supply (California State Health and Welfare Agency, 1981).

Worldwide herbicide consumption has outgrown insecticide consumption. Herbicides now represent half of the pesticide expenditures in both the U.S. and the world (Lacey, 1985; Riggleman, 1986). The majority of herbicides are marketed for crop applications, and herbicides for corn and soybean crops represent over 70 percent of the total U.S. herbicide market (Riggleman, 1986). Application to corn and soybeans represented only 23 percent of the herbicide usage in 1984 on the world market (Watterson, 1988).

Selectivity

Products that eliminated a wide range of vegetation in a large number of situations, referred to as broad spectrum herbicides, were used extensively in the past. There has been a general trend of moving towards products that are aimed at selected plant species (Hay, 1982; Riggleman, 1986). Selectivity is essential for agricultural applications but railroads benefit more from broad spectrum herbicides that remove all vegetation in the right-of-way (Anonymous, 1975b).

The trend toward selective herbicides is directly related to the expense of testing and marketing new herbicide compounds. A greater demand for selective versus broad spectrum herbicides exists in agriculture which is the largest herbicide user group, and research has been directed in that area (Anonymous, 1975b). Because selective herbicides do not control a wide range of vegetation problems, applicators need to be aware of weaknesses in herbicide effectiveness so they can compensate for them in their vegetation control programs (Anonymous, 1985b). One way the limitations of individual herbicides have been overcome is to mix them together before application, or to use several applications of different chemical formulations.

Application Rates

As technology has increased, herbicides have been developed that require smaller and smaller doses to provide effective weed control. New synthetic formulas that control weeds at application rates of less than two grams per acre have been developed (Riggleman, 1986). Older formulations may require application rates up to twenty pounds (9,079 grams) per acre (Bullington, 1987). At a two gram per acre application rate the herbicide is spread over an acre at a depth of only one molecule (Riggleman, 1986).

Application Volumes

In the past, volumes of 120 to 150 gallons per acre were common for herbicide applications. Now volumes as low as 30 to 50 gallons per acre and normally 50 to 80 gallons per acre are used. Ultra-low volume herbicides which have application rates as low as 0.5 gallons per acre are also in use (Caswell, et al., 1981) Research has been done on the effectiveness of low volume herbicide application and on alternative application techniques (Owen, 1984). Other tests have been done to determine which herbicides, at what application rates, eliminate specific plant species (Holt and Kosinski, 1985; Holt, et al., 1989).

Environmental Concerns and Testing

Environmental concerns have caused the Environmental Protection Agency (EPA) to impose stricter regulations on herbicide registration and testing. Organizations such as the Audubon Society and the Sierra Club have applied pressure to the government agencies in order to force pesticide manufacturers and users to limit risk to wildlife, prevent crop contamination, and to limit the possibility of pesticide residue entering into milk and flesh of livestock (Anonymous, 1973b). Because of this, the cost of health and safety aspects of regulating herbicides has more than doubled during the last five years (Riggleman, 1986). In 1953, to develop and test a new pesticide would have cost approximately $1.2 million dollars, and would have required the testing of 10,000 different compounds. The cost listed in 1973 for research and development of a pesticide is between six and twelve million dollars with a research time of up to ten years (Anonymous, 1973b) In 1987, to develop and test a new pesticide took on average seven years, cost approximately $45 million dollars, and required the analysis of 20,000 or more chemicals (Watterson, 1988). When the cost increase from inflation between 1973 and 1987 was considered, the cost to develop a pesticide still almost doubled between those years.

Testing and developing herbicides is expensive because manufacturers must obtain a wide variety of information in order to create a herbicide data label. The label subsequently becomes a legal document produced by the manufacturer for the protection of the consumer using the herbicide (Hay, 1982). The label must specify the effect of the herbicide on humans, animals, and the environment as well as the effect of sunlight and soil on the chemical compound. The potential for eye and dermal irritation and the lethal dose rate at which fifty percent of the test animal population dies when administered an oral dose of the herbicide (called an LD-50) must also be determined. The amount of information that is needed to register a herbicide has increased as the public has become more vocal about concerns over chemical use.

Herbicide and Plant Interactions

The manner in which a herbicide works influences what type of vegetation it will eliminate, how and when it should be applied, and the potential problems inherent with the herbicide. Two general categories of herbicides are selective and non-selective. Selective herbicides target one particular plant species or type, such as broad-leaf vegetation and will not harm other types of plants at application dosages (Swan, et al, 1988). They may be truly selective by chemical formulation or selective by placement (Ware, 1978). Examples of selective herbicides are trifluralin, atrazine and 2,4-D.

Non-selective herbicides will kill all species of plants without discrimination, but some species will require a higher dosage than others to effectively eliminate them (Swan, et al, 1988). Bromacil, ammonium sulfamate, and tebuthiuron are examples of non-selective herbicides. Aside from the species of plant that the herbicide targets, herbicides eliminate vegetation by different methods. There are contact herbicides and translocated herbicides.

Contact Herbicides

Contact herbicides are non-selective and are applied in liquid form in either a water or an oil-based solution. Some herbicides dissolve more readily in oil such as kerosene or organic solvents like xylene, which acts as a carrier fluid for their application (Anderson, 1983). Because of the expense involved and the potential toxicity of the solvents, oil-based solutions are not as common as water-based solutions.

These herbicides work by penetrating the protective layers of the leaf and being absorbed into the intercellular spaces of the plant. Once in the spaces, the herbicide attacks the cells and the plant protoplasm, and eventually kills the leaves. Contact herbicides work relatively quickly and results can be seen shortly after application. Plants that have been treated with contact herbicides look like they have been scorched (Cole, et al., 1987). Some examples of contact herbicides are cacodylic acid, paraquat, and DNBP (Caswell, et al., 1981; Cole, et al., 1987).

Wetting agents, called surfactants, are used with contact herbicides to ensure that the liquid spreads evenly over the entire leaf surface. This is essential to effective plant kill (Archdeacon and Ellsworth 1985; Bandoni, 1987). Contact herbicides have been referred to as "chemical mowers" because they only affect the area of the plant that is covered with the herbicide (Swan, et al, 1988).

Translocated Herbicides

Translocated herbicides may consist of systemic hormone herbicides or systemic residual herbicides, and can be selective or non-selective. Translocated herbicides work more slowly than contact herbicides, but provide better control of deep rooted or perennial weeds (Cole, et al., 1987). They are absorbed by the plant through the leaves, roots, and stems. Systemic hormone herbicides include photosynthesis inhibitors, cell growth inhibitors, and plant growth regulators.

Photosynthesis Inhibitors

Photosynthesis inhibitors eliminate vegetation by upsetting the food producing systems of the plants by interfering with chlorophyll production. They are more effective on seedlings than established plants. When applied during preemergence, the plants sprout but as soon as the stored food supply for the seedlings is gone, the plants die. Some examples of these herbicides are Bladex, Hyvar x, Velpar, and Karmex (Cole, et al., 1987).

Cell Growth Inhibitors

Cell growth regulators are systemic hormone herbicides that cause plant cells to develop abnormally and prevent cell division in developing roots and shoots. Examples of these herbicides are chloropham, butlyate, and dalapon (Cole, et al., 1987).

Plant Growth Regulators

Another type of systemic hormone herbicides are plant growth regulators. These herbicides are synthetic chemicals similar in structure to naturally occurring plant hormones, and can be selective or non-selective. Growth regulators have little contact effect and are absorbed through the vegetative body of the plant. They can be adsorbed by the fleshy stems of tough broad-leafed perennials or by woody stems of vines and brambles. Growth regulators are transferred by the plant vascular system to the growing points, and once located there cause massive interference with normal plant cell division and physiology. The herbicide may cause rapid plant growth or a retardation of growth until the plant system is unable to function properly. Once it can no longer sustain itself the plant dies (Caswell, et al., 1981; Archdeacon and Ellsworth 1985). Within seven to ten days from application of growth regulators the plants start to become puckered and visibly malformed (Cole, et al., 1987). Examples of plant growth regulators are gibberellic acid, maleic hydrazide, and ethephon (Caswell, et al., 1981).

Residual Herbicides

Translocated herbicides may also work through the plant root system. These herbicides are called systemic residual herbicides and are applied to the soil and absorbed by the root systems of the plant (Swan, et al., 1988). Once absorbed they move upward toward the growing points and plant foliage to kill the plant (Cole, et al., 1987). They are the most expensive component of herbicide mixtures, and are most effective against new growth when young plants are under the greatest natural stresses in the early part of the growing season (Archdeacon and Ellsworth, 1985; Cole, et al., 1987). Residual herbicides remain active in the soil after application (Cole, et al., 1987), but even though these are considered residual herbicides, environmental forces break down 80 to 90 percent of the product during the first growing season (Archdeacon and Ellsworth, 1985).

Environmental Influences

A working knowledge of soil variations, plant species, climate conditions, and biological processes are also needed to develop an effective herbicide application program (Anonymous, 1975b). Soil type, temperature, rainfall, and microorganisms are environmental influences that may enhance or reduce the amount of vegetation that a herbicide is able to destroy. Table 1 summarizes positive and negative influences that environmental factors have on herbicide effectiveness.

The soil type does not effect contact or systemic hormone herbicides, but influences the action of systemic residual herbicides. Because these types of herbicides are dependent on action through plant root systems, the physical adsorption of the herbicide is important. Minerals, organics, and soils with high clay contents have numerous electrically charged sites. These readily bind herbicides and make them unavailable to the plants (Cole, et al., 1987; Swan, et al., 1988; U.S. Department of Agriculture, no date). Since sand or silt has fewer charged sites to attract herbicides, they allow the herbicides to move quickly to the root systems but are unable to bind the herbicides in the soil. Thus the herbicide is effective for a shorter duration than if it remained in contact longer with the plant root system (Archdeacon and Ellsworth 1985; Swan, et al., 1988).

Temperature

Soil and air temperatures influence the effectiveness of a herbicide because plant growth and herbicide degradation are functions of temperature. At high temperatures, herbicides will readily degrade in soil, but the plants can actively adsorb the herbicide. Increased temperature, if there is adequate moisture, may cause the herbicides to control weeds more quickly because of greater plant activity (Cole, et al., 1987; Swan, et al., 1988;). Conversely, when it is cold and plants are in a dormant stage, systemic hormone herbicides may have little affect on the plants.

Some contact herbicides are noted to have little effect when they are applied at temperatures lower than 75°F or 80°F (Archdeacon and Ellsworth, 1985). Herbicides are said to react more effectively with plants when applied at temperatures of 70°F or greater. A 10°F temperature increase from 60°F to 70°F generally doubles the rate of chemical reactions (Cole, et al., 1987).

Rainfall

Adequate rainfall promotes plant growth, making them more susceptible to chemical treatment. For herbicides that enter plants through the root zone, it is necessary to have a minimum amount of moisture to make this possible. A heavy dew can provide adequate soil moisture to facilitate good plant uptake of residual herbicides (Swan, et al., 1988). The longer the herbicide remains on the soil surface, the greater degradation it experiences due to evaporation and possibly photodegradation. If the chemical application is followed by three weeks without rain all vegetation control from the herbicide may be lost (Cole, et al., 1987)

Excessive rainfall can cause problems however, because the herbicide may leach rapidly through the soil and be unavailable for uptake by the plants (Cole, et al., 1987; Swan, et al., 1988). This may also result in infiltration of the herbicide into groundwater. A heavy precipitation may even cause herbicide runoff which transports the chemicals out of the target area and can damage non-targeted vegetation. Foliar applied herbicides are more effective when an eight hour period without rain follows the application so that the herbicides are absorbed into the leaves (Cole, et al., 1987).

Microorganisms

Soil microorganisms contribute to the breakdown of herbicides in the soil. They absorb and metabolize herbicides, using the organic matter as a food source. This effects residual herbicides because the majority of the product is either absorbed by the plant or used by microorganisms after the first growing season. Application rates that are high enough to perform for more than one season are not economically feasible (Archdeacon and Ellsworth, 1985).

Table 1: Summary of Environmental Influences

Key:
+ Positive Influence
- Negative Influence
* Depends on Rainfall Conditions

Environmental Factor	Translocated Herbicide	Contact Herbicide
Temperature < $70^{o}F$	-	-
Temperature 70 - $80^{o}F$	+	+
Temperature > $80^{o}F$	*	-
No Rainfall	-	+
Moderate Rainfall	+	-
Excessive Rainfall	-	-
Wind > 5 mph	-	-

Herbicide Formulations

Herbicides are available in one of several forms which influence the types of application and the equipment that is required to apply them. They are manufactured in both a liquid and a dry powder form. Liquids are found in wettable powder, water soluble powder, or in liquid suspension form. Alternatively, the dry forms may come in grains or pellets which can be spread on the ground.

Herbicide Application

Herbicides can be applied to a right-of-way in a number of ways. Liquid herbicides are applied with spray trains, hi-rail vehicles, helicopters, or a backpack sprayers. Herbicides can be applied after all the foliage has dropped off woody species. This is called dormant stem application and the branches of the shrubs are completely covered with herbicide for control (Cole, et al., 1987). Woody species may be controlled with herbicides following mechanical cutting. The herbicides are applied on the cut stems of the shrubs as a cut surface application technique. Best results occur when the herbicide is applied immediately after cutting (Cole, et al., 1987). Dry herbicide formulations can be applied by several types of spreaders.

Liquid Applications

For high volume applications of liquid herbicide solutions, a spray train or a hi-rail sprayer car can be employed. On-track herbicide applicators are more commonly used than off-track applicators in railroad applications; farmers have developed many unique variations of herbicide sprayers that are used in off-track applications (Mowitz, 1987).

Spray Trains

Spray trains are able to handle large qualities of the mixture (about 10,000 gallons) (Holt and Osburn, 1985; Anonymous 1986c). Spray trains lose much of their efficiency on short branch lines and in terminal areas, being best suited for end to end mainline applications (Holt and Osburn, 1985; Brauer 1983). These trains have the capability to treat both the roadbed and the shrubs and trees along the right-of-way in a single application, potentially providing a substantial savings (Anonymous, 1986a). A recent innovation is the ability to apply two different herbicide mixtures simultaneously in order to save time (Brauer, 1983). A spray train uses a locomotive to pull the herbicide tanks and spraying apparatus; this requires a crew to operate the locomotive. The trains can travel at a speed of ten miles per hour when they are spraying both the roadbed and the right-of-way, and a speed of fifteen miles per hour for roadbed application only. The speed that the locomotive travels influences the rate of herbicide application (Holt and Osburn, 1985). The speed may also be restricted by regulatory control agencies to reduce or minimize drift.

Hi-Rail Vehicles

Another way to apply liquid herbicide solutions is by means of a self-propelled rail vehicle, called a hi-rail, with a tank and sprayer apparatus mounted on it. A hi-rail car requires fewer people for operation than a spray train, but has a smaller tank capacity, typically 1,000 to 3,000 gallons (Holt and Osburn, 1985). The hi-rail unit must be filled several times daily, and time may be required for travel back and forth to get water. Capabilities to apply herbicide to both the right-of-way and the roadbed simultaneously may also be available with some hi-rail vehicles. The trend toward using lower volume herbicides which increase the time between refills of this equipment (Holt and Osburn, 1985) make the hi-rail vehicle more feasible (Anonymous, 1977; Brauer, 1983).

Along with the reduction in total application volume, less of the herbicide may now be used. For example, the herbicide Oust manufactured by E.I. DuPont Company has a chemical application rate of four to eight ounces per acre. This reduces the bulk of chemicals that railroads haul for spray programs as well as improving the logistics because less frequent stops are required to replenish the chemical supply. There are also fewer empty herbicide containers for disposal (Anonymous, 1984c).

Hi-rail cars are competitive with trains in terms of total cost but for large scale operations they have logistic problems in getting water (Brauer, 1983). SSI Industries, Inc. (a subsidiary of Mobley Industries) owns a spray train which took three days, during the summer of 1985, to apply dual treatment to a Midwest mainline roadbed and right-of-way for over 200 miles of track. To apply herbicides to the mainline only using a hi-rail car was formerly a two week operation. If the hi-rail car was not able to apply herbicides to both the roadbed and outer right-of-way simultaneously, two passes of the hi-rail would be needed. Dual treatment of roadbed and right-of-way provides substantial time and cost savings for railroads (Anonymous, 1986a).

With the advent of improved spray nozzles, herbicide applications are more precise than in the past. Controlled droplet applicators (CDA) and electrostatically charged droplets use one tenth to one fortieth of the volume of herbicide to produce the same level of control as other nozzles (Parham, 1982). An alternative technique is used with a hi-rail car to apply root active herbicides mixed with a low volume (ten to twenty gallons per acre) of water. The herbicide is applied in strips or bands parallel to the track, and about four feet apart so that there is an area between the strips that is not treated with herbicide. By applying herbicide this way, desirable ground cover is preserved and drift problems are reduced. This technique is effective for treating shrubs but care should be taken to keep herbicide strips off of the root zone of trees outside the right-of-way (Brauer, 1983).

Helicopters

Helicopters are sometimes used to apply liquid herbicides for large scale operations. This type of application is best suited in areas which on-track spray trains are unable to reach because of the distance from the track, or off-track spray vehicles are hampered by rough terrain. A useful application for helicopter spraying is along power lines, located a considerable distance from the track, to control vegetation underneath the lines where spray equipment cannot reach. Helicopter herbicide application is not as efficient as spray train application and the herbicide tends to drift (Brauer, 1983).

Backpack Sprayers

Backpack sprayers have been used to apply herbicides for small scale operations, and have up to a five gallon capacity (Cole, et al., 1987). A person wears the spray apparatus and then aims the nozzle at the proper locations. Backpack sprayers are used to control woody species through basal bark herbicide applications. The circumference of the lower 12 to 14 inches of the shrub or tree is covered with herbicide (Cole, et al., 1987). It is obvious that backpack spray application of herbicides is labor intensive but may be an effective treatment method in some circumstances such as around signs or posts or in places where accurate herbicide placement is essential.

Dry Applications

Dry application herbicide mixtures come in dust or granule form. Dusts are dry powders of a very fine consistency. Commonly, 0.5 to ten percent of the mixture is active herbicide ingredient and the rest is a filler or carrier material (Caswell, et al., 1981). Granules, or pellets, are larger in size than herbicide dust particles, and range from 0.3 to 1.33 millimeters in diameter (Barlow, 1985). They typically contain from two to twenty percent active herbicide ingredient (Caswell, et al., 1981).

Herbicide formulations that consist of particles that are sized between a dust and a granule are termed microgranules, and range from 0.1 to 0.3 millimeters in diameter (Barlow, 1985). An advantage of granular or pellet forms of herbicides over liquid forms is that pellets are able to penetrate dense foliage over which it may be difficult to effectively spread liquid herbicides.

Additionally, slow release of residual herbicide from the pellets may provide effective long term control (Caswell, et al., 1981).

A variety of material spreaders are used in order to apply dry herbicide materials such as pellets or granules. Seed spreaders, converted from farming applications, are used to apply granules where mechanical spray equipment cannot reach (Brauer, 1983). The calibration for this type of equipment is less precise than for other types of spray applications (Holt and Osburn, 1985). An air gun can be used in a technique similar to sandblasting to "shoot" herbicide pellets up to fifty feet. The air gun is mounted on a flat-bed hi-rail truck, and this type of applicator is suited for spot treatments of scattered brush or for vegetation along fences (Brauer, 1983).

Timing of Herbicide Applications

The effectiveness of a herbicide is influenced by the time in the plant growth cycle that the product is applied, as well as the type of herbicide. Growth regulators and contact herbicides are applied at different times than residual herbicides for the most effective results. Herbicides can be applied before the weeds sprout in the spring, in the pre-emergence phase. This is usually when residual herbicides are applied so they can go directly into the soil and work to inhibit germination and eliminate underground root structures of plants (Lacey, 1985). By applying the herbicide at this time, it assures that the most herbicide will be available to affect the plant when it is at its weakest development time, just ready to emerge from the soil. Usually this type of application results in "bare ground" control where all species of vegetation are eliminated. However, to kill all the vegetation requires a high chemical dosage which is expensive (Archdeacon and Ellsworth, 1985).

Herbicides are also applied to weeds once they have already sprouted. Post-emergence herbicide application is used with contact or growth regulator herbicides to kill weeds once they have emerged. If the weeds are not eliminated at an early growth stage, seeds may be produced which will germinate the next year, or the plant may not be growing actively enough for the growth regulator to kill it. The post-emergence method of application is the most common for vegetation control programs on railroads (Archdeacon and Ellsworth, 1985). A summary of the influence of plant growth stage on herbicide effectiveness is shown as Figure 2.

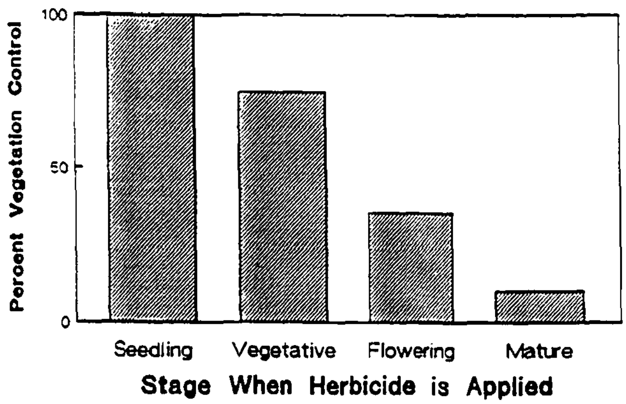


Figure 2: Weed Control of Annuals and Biennials. Adapted from Stewart, 1986.

Cost of Herbicide Application

The cost to apply herbicides to railroad rights-of-way is influenced by a variety of factors including the chemical formula that is used, the amount of the chemical needed to control vegetation, and the timing and frequency with which it must be applied. Railroads must determine the degree of vegetation control desired, the pattern of herbicide coverage, and the portion of the railroad line to be treated with herbicide (Anonymous, 1975b). In recent years chemicals have become the dominant means to address vegetation management problems on railroads (Archdeacon and Ellsworth, 1985; AREA, 1988). This is primarily because they have been viewed as the most economical method to obtain satisfying vegetation control (Brauer, 1983). Railroad to railroad annual spray costs vary greatly but they tend to be lower in the western United States, compared to the south. Greater amounts of rainfall in the south enhance vegetation growth, necessitating more frequent chemical applications (Anonymous, 1987c). Costs to apply herbicides vary widely. Application costs were reported to be between $50 and $60 per acre for roadbed and yard herbicide applications in 1977 (Anonymous, 1977). During 1983 the cost ranged from $25 to $125 per acre, depending on the vegetation species and the weather conditions (Brauer, 1983).

Problems With Herbicides

Measures should be used to reduce potential problems with the use of herbicides. When herbicides are applied the chemical may drift outside of the zone of application. Drift consists of small drops of liquid herbicide or dust from dry formulations. Drift may also occur when herbicides volatilize and the fumes are carried outside of the target area. Herbicide volatilization is more likely when temperatures are above 75^{o}F or when there is low humidity (Cole, et al., 1987). Drift may cause destruction of non-targeted vegetation that is not on the railroad's property.

Drift can be reduced by using a low pressure spray nozzle, low mounted booms or nozzles with large orifices that produce large drops (Holt and Osburn, 1985). The traditional high pressure fire hose type of nozzles have been replaced with low and medium volume applicators for this reason (Brauer, 1983). Low-drift adjuvants (drift inhibitors) that can be added to the herbicide mixture are readily available to help reduce drift (Bandoni, 1987). Additionally, state regulations may specify a maximum wind speed and/or maximum applicator speed at which herbicides can be applied. In situations where drift would cause problems specific herbicide formulations can be used that have a lower drift potentials, or will not result in much damage if they do drift. This may be important if the railroad right-of-way is close to cropland or ornamental shrubbery (Holt and Osburn, 1985).

Another problem with herbicides is that they may cause "burnout", where all of the vegetation turns brown and dies but remains standing. This is unsightly and may cause public outcry in populated areas. In this situation some other form of vegetation control is usually substituted for herbicides or herbicides are applied in the pre-emergence vegetative stage (Brauer, 1983).

There are also the possibilities of air and water pollution when herbicides are applied. If there is a heavy rainfall before adsorption of herbicides occurs, the herbicide can run off in the rainwater. Aquatic organisms may be damaged by the herbicide if it reaches a water body, or it may leach into the drinking water supply and potentially be consumed. Occasionally herbicides have been detected in water, but they are usually in low concentrations and occur infrequently (McWhorter, 1982; U.S. Department of Agriculture, no date).

Non-Herbicides

A number of chemical methods that are not typically thought of as herbicides have been used to eliminate vegetation. Two examples of these are salt and oil. Salt in the dry form or as ocean water has been tried as a method to eliminate vegetation. There is little research on the effectiveness of this method of vegetation control but generally high concentrations of salt are needed to eliminate the vegetation. One drawback to this method is that salt is readily dissolved in water and thus can move through soil very quickly posing a potential surface and groundwater contamination threat.

Oil and grease have been used rather informally as means to control vegetation. Usually waste oil and grease are poured over troublesome plant species in spot applications to eliminate them. The potential environmental impacts of this practice are that hydrocarbons enter the environment. Non-herbicide chemicals that are used for weed control are fairly uncommon and not used on a wide scale basis.

PHYSICAL VEGETATION CONTROL

There are a number of ways to remove unwanted vegetation mechanically from the right-of-way. Shrub or grass cutting machines can be used along with bulldozers that scrape away the vegetation layer. Traditional railroad maintenance equipment such as a ballast regulator, an undercutter/cleaner, or a spreading and ditching machine can also play a role in eliminating vegetation. The practice of cutting vegetation along the right-of-way was the original method of vegetation control used by railroads. Hand labor was employed to cut vegetation until the shortage of an inexpensive work force made the practice uneconomical. After World War II, railroads started using tractor mowers, and much railroad right-of-way was still being mowed until recently. Brush cutting, or other mechanical methods, are widely used in conjunction with or as an alternative to chemical treatment because of their immediate results (Brauer, 1983).

Vegetation Cutting Machines

Timing is an important aspect when using mechanical means to control vegetation (DeVault, 1987). If the vegetation is cut at a time when it has expended most of its reserve energy by producing above ground shoots, then cutting may serve to kill the plant. If the plant has enough reserve energy stored within the root system it may be able to survive the cutting. For example, cutting winter broadleaf vegetation, which germinates in the fall, matures in the summer, and dies in the fall, works well in the springtime while these plants experience their maximum growth and have little reserve energy left to resprout (Lee, 1985; Swan, et al., 1988). With mechanical cutting methods, there is a possibility of rapid regrowth of suckering and sprouting species because the root system of the plant is not eliminated. Cutting shrubs may produce a more dense secondary growth than that which existed prior to cutting (Archdeacon and Ellsworth, 1985; Brauer, 1983). No control is provided for vines, and this process may actually encourage their growth (Brauer, 1983). In the outer right-of-way the goal in vegetation management is often to reduce the height of the growth, so the sprouting of new buds may be acceptable. Within the roadbed, increased density from regrowth of the woody species may be detrimental to the vegetation control program.

Mowing

Clipping or mowing is a method of vegetation control that is used in the outer right-of-way but not in the immediate roadbed area of the track. This form of vegetation control for herbaceous species is commonly used along roadways and has been found to control broadleaf plants more effectively than grasses. Best results are achieved when the vegetation is 30 to 45 inches in height at cutting time. If vegetation is too small then only the tops will be removed and branches and root systems have the chance to develop lateral buds. Some sources feel that the plants should be clipped as close to the soil as possible and before they have a chance to produce seeds (Lee, 1985), while others contend that no more than one third of the plant height should be removed in one mowing in order to reduce the risk of killing plants that provide erosion control and inhibit other species from germinating (Cole, et al., 1987). The growth stage of the plant should be taken into consideration in order to develop an adequate vegetation control program (Lee, 1985).

A 1986 survey of state highway department roadside maintenance programs, conducted by the Transportation Research Board, revealed that most state highway departments mow their right-of-way two and a half to three times yearly in order to achieve effective vegetation control (Johnson, 1988).

In urban areas, mechanical mowing of vegetation, on levees, is one of the most expensive activities on a cost-per-acre basis. In 1985 the average approximate labor for this mowing was 14 labor-hours per acre, with a high of 21 labor-hours per acre. To burn the vegetation on the levees required four labor-hours per acre and to apply chemicals took only 0.5 labor-hours per acre (Fitzgerald, 1986). Mowing has also been sited by highway departments as the most intensive roadside maintenance activity in terms of time and cost per acre (Cole, et al., 1987).

Brush Cutting

Vegetation along the right-of-way can be controlled using either on- or off-track brush cutting equipment. Brush cutters have a rotating head at the end of an extendable arm that cuts the trees and shrubs (Hay, 1982).

On-Track Brush Cutters

Track mounted brush cutters are self-propelled and can reach 22 to 30 feet out from the track centerline and remove trees with six to eight inch diameters (Archdeacon and Ellsworth, 1985; Brauer, 1983). A special brush cutter for removing shrubs under transmission line wires was used on

Burlington Northern in southern Illinois (Anonymous, 1970a). It had a reach of 52 feet from the centerline of the track and was capable of a 45 to 110 degree arm swing to accommodate for rough terrain. The productivity rate for a 1970 prototype was 1.12 miles of right-of-way cut per day with an average width of 28 feet (Anonymous, 1970a).

A 1986 productivity estimate of CSX Transportation Incorporated's Chessie System component reported that 0.89 miles of track with a total width of 24 feet was cut per day by their on-track brush cutter. The total use of their time was divided into 44 percent production time, 56 percent delays including 15 percent maintenance and repair with the remainder of the delays due to train delay, crew travel, and miscellaneous items (Sheahan, 1988). The efficiency of on-track brush cutters varies with a given situation and is limited by the lateral reach of the equipment and by the density of other rail traffic (AREA, 1988).

Railroads tend to use this type of equipment to remove vegetation in areas beyond the chemically treated swaths which are commonly twenty feet on each side of the track centerline (Anonymous, 1989). By removing the shrubs, brush cutters help reduce barriers for blowing and drifting snow and improve visibility along the track (Archdeacon and Ellsworth, 1985).

Off-Track Brush Cutters

Equipment which operates beyond the railroad track can also be used to control unwanted vegetation. Off-track equipment can adequately eliminate vegetation but may be unable to operate in wet areas (Brauer, 1983). The right-of-way should be prepared to allow operation of off-track equipment as the equipment must travel on a relatively smooth, unobstructed surface. Preparation increases the costs of using off-track equipment, reducing its desirability (Anonymous, 1989).

Both rubber-tired and crawler type brush cutters can be used. Rubber-tired brush cutters operate over rough terrain but their movements are restricted in swampy areas. Crawler type brush cutters can be used successfully in the wetter areas (Archdeacon and Ellsworth, 1985). One advantage of off-track equipment is that it may not be influenced by train traffic, but the area covered per hour by this equipment is frequently less than that of on-track equipment (AREA, 1988). Off-track equipment does have the advantage of a greater reach than equipment restricted to travel on the rail.

In areas where brush has been allowed to grow unchecked for a number of years, an on-track brush cutter has been cited as the most economical and practical way to begin a cleanup program (Archdeacon and Ellsworth, 1985), but the cost of mechanical brush control is usually greater than that of chemical brush control once the brush has been removed initially (AREA, 1988). The cost of the initial vegetation control effort for any means of control is greater than the cost of maintaining the vegetation at acceptable levels. There are experimental programs in progress to help recover the cost of brush cutting by shredding the brush in the right-of-way and selling the chips as fuel or paper pulp (Brauer, 1983).

Bulldozers and Scraping Equipment

Vegetation along the track, but not directly under the ties, can be eliminated with bulldozers, ballast regulators or other scraping equipment. Disturbing the soil by removing the top surface layer is one of the oldest methods of non-chemical weed control. This process eliminates weeds but also may bring buried seeds to the surface so they can germinate. In many cases, the majority of the seed pool is buried in the upper three inches of soil so that scraping to this depth removes most of them, and not many new seeds are brought to the surface (Lanini, 1987). This method of "shallow cultivation" is used in many crop applications in the arid west (McEachern, 1985). Disturbing the soil in the early spring should be avoided as it helps to warm the soil and causes the weeds to develop shoots earlier in the season

(Klor and Klor, 1987). Bulldozers that are used to scrape away vegetation are able to clear shrubs under wires and in other difficult areas, but it is a costly method. The increased cost is at least partly offset since vegetation control with bulldozing usually lasts longer than vegetation control from cutting methods (Brauer, 1983).

Hand Clearing of Vegetation

Vegetation may be removed by means of hand cutting or pulling out the vegetation. Hand cutting is similar to cutting using mechanical equipment except that it is more labor intensive and can be accomplished in the area between the ties where mechanical cutting machines cannot reach. This type of vegetation control is most applicable in the roadbed area where removal of all vegetation is desired, and in areas where dense vegetation is not present. Hand cutting is most effective on annuals and on woody species that do not readily resprout, especially conifers.

Pulling out the vegetation by hand is an effective means of control if the soil is loose enough or the roots are shallow enough to allow the majority of the root system to be removed with the plant shoots. In some plant species, for example horsetail, it is very difficult to remove enough of the root to prevent regrowth of the plant. Younger plants especially are much easier to completely uproot by hand.

Some states use convict labor or youth corps for hand cutting or weeding programs. A safety problem may be created by the work crew along the track, especially if they are working in the roadbed area, and measures must be taken to insure their safety. This type of vegetation program has more flexibility than on-track mechanical cutting programs as the workers can easily get off of the track for traffic to pass whereas on-track mechanical equipment must pull into a siding to clear the railway.

Undercutting

Machines that have been traditionally used for railroad track maintenance may be used to control vegetation along the track in conjunction with standard mechanical vegetation control equipment. This equipment is most effective in the ballast area, between the ties and directly along the track shoulders, because these are areas where traditional mechanical vegetation control machinery has difficulty reaching. There are a number of track maintenance machines that may be modified or used in ways that they were not originally intended, for vegetation control. Examples of machinery that may be used in this manner are undercutters, ballast regulators, and tampers.

An undercutter traditionally is used in track renovation programs to upgrade the quality of ballast and not specifically to remove vegetation. It may be used in an undercutting/cleaning process where the ballast is cleaned and then replaced, or to completely remove the top layer of ballast without replacement. Undercutting is only an economical option on well maintained track (Anonymous, 1974).

An undercutter is not used alone but rather is part of a team of equipment used to maintain the track. First, a tie gang must go through to replace old ties and a tamper may make a pass to loosen up the ballast in order to reduce wear on the undercutter chain and increase productivity. Sometimes the shoulders are plowed with a ballast regulator before undercutting to keep water from getting trapped in the shoulder area (Anonymous, 1976). Then the undercutter makes a cut and laborers follow to pick up ties that fall off of the rail before they are buried by the ballast. These ties will have to be replaced in order to maintain track stability. A section of ballast from six to twelve inches deep is removed from under the ties by buckets connected to an excavating chain (Anonymous, 1975a; Archdeacon and Ellsworth, 1985). If the machine is an undercutter/cleaner, then the excavated material is placed on a vibrating screen so undersized particles are removed and discarded. The good ballast is returned to the track section (Hay, 1982; Archdeacon and Ellsworth, 1985). Wet ballast cannot be screened as particles will not pass through the screen.

When undercutting in areas of highly contaminated ballast, 50 percent of the ballast material may be removed, requiring substantial ballast replacement (Anonymous, 1976). This waste material is either dumped on the track shoulder or onto conveyors which transfer it into air dump cars. A bulldozer, motor grader, or a ballast regulator may be used to recreate the track drainage system when the unwanted material is placed on the shoulder. The material may be also used to strengthen the roadbed shoulders (Anonymous, 1970b; Archdeacon and Ellsworth, 1985).

Once the actual undercutting operation is complete, a tamper follows to recompact the ballast around the ties. The track is not suitable for heavy rail traffic until it has been tamped and compacted (Anonymous, 1984a). Following the tamping and compacting equipment, a ballast regulator grooms and dresses the track in order to facilitate good drainage and to level out the edges (Anonymous, 1976). During the undercutting process the track elevation is not increased, and thus it is suited to areas where an elevation increase would be detrimental due to physical conditions or inadequate embankment support. When the undercutting procedure is complete, a near perfect track cross-section is created (Archdeacon and Ellsworth, 1985).

Undercutter/cleaners may be owned by private railroads but they are also available for contract work. Knox Kershaw Inc. and Plasser American Co. are the two principle contractors that do undercutting-cleaning work (Archdeacon and Ellsworth, 1985). In 1975 ballast undercutter/cleaners were one of the most expensive pieces of railway maintenance equipment (Anonymous, 1975a). For undercutters both the initial capital investment and the maintenance and operating costs are high (Hay, 1982).

Production rates for undercutter/cleaners vary depending on numerous field conditions. In 1970, a ballast cleaner working on the Missouri Pacific Railroad near Earle, Arkansas had in-field productivity rates of 720 feet per hour for a 12 inch cut and 866 feet per hour for a 10 inch cut. Five-hundred and eighteen and 550 cubic yards of material were removed respectively. The manufacturer claimed that under optimum conditions for a ten inch cut this machine had a working speed of 900 feet per hour (Anonymous, 1970b).

The undercutting process is most applicable for vegetation control in areas where the track is in need of refurbishing such as replacing or cleaning the ballast, or re-alining the track. An undercutter/cleaner helps control vegetation by removing vegetation in the difficult to reach areas between the ties and along the shoulders. It also serves to control vegetation by decreasing the availability of fine particles and moisture in the ballast that are needed for plant growth.

Ballast Regulator

Ballast regulators, like undercutters, are used in track maintenance procedures but may secondarily control vegetation. A ballast regulator's main function is to level and groom the ballast; it may spread new ballast along the track to fill in holes or push excess ballast out of the tie area to the shoulders. A ballast regulator is also able to pull in materials outside of the tie structure to be used in the center of the track. In the final phase of the ballast regulating procedure the machine sweeps ballast particles off the tops of the ties with a very stiff brush so that they are visible, and to facilitate easy walking along the rail (Archdeacon and Ellsworth, 1985; Hay, 1982).

Ballast regulators are often used with a fleet of equipment in the undercutting/cleaning process. In that instance they are used to loosen the ballast before the undercutter makes a cut, and to groom the track once the procedure is complete. Ballast regulators can be used for vegetation control by scraping off the vegetation in the shoulder area, and pushing it to the outer portion of the roadbed. This disturbance may or may not kill the vegetation. The sweepers used for removing ballast from the ties can control vegetation by removing plants and substrate, or by causing physical damage to the vegetation. There are no cost or performance data in the literature for this vegetation control method.

One added benefit of ballast regulators is that some of the machines can be converted to snow plows in the winter months. This is accomplished by attaching a plow to the front of the machine or adding a snowblower to the back. Productivity is increased as the equipment is in use for a longer time each year. An example of this is Canadian National Railway (CN) which uses a high productivity ballast regulator the entire year (Anonymous, 1984b). Snow plowing may also play a role in vegetation control by damaging vegetation, especially woody species.

There are a number of companies that manufacture ballast regulators and the productivity rates vary with the type of equipment and the way they are used. Kershaws's ballast cleaner has a production rate of about 5,000 feet per hour and is capable of regulating ballast along the track shoulders and of scarifying the ballast at the end of the ties in order to break any mud seals that have formed (Anonymous, 1987b).

Inhibiting Vegetation Growth

One theory for vegetation control is that not only existing vegetation should be removed but the likelihood of vegetative regrowth should be reduced. Replacing old ballast with cleaner ballast, adding a geotextile to the track structure, and asphalting the ballast area are all methods that aim to reduce the amount of vegetative regrowth.

Replace with Cleaner Ballast

Over the years ballast tends to wear and the amount of fine particles in the ballast increases. These fine particles, as noted in the Importance of Adequate Drainage section, tend to increase the moisture carrying capacity of the ballast and thus improve the growing environment for plants. The amount of fine particles and moisture is decreased and existing vegetation is eliminated by removing old ballast. If the new ballast is free from fine particles and seed then the amount of vegetation able to grow in the ballast area is reduced. When new ballast is added it should be of good quality to meet both the strength and gradation specifications of the railroad so that it does not easily degrade and produce fine particles in which vegetation can grow (Zarembski, 1989). Studies have been done to help railroads develop an accurate procedure that determines how fast a specific type of ballast will degrade under repeated loadings (Chrismer, 1988).

In areas of little excess ballast, new ballast is dumped onto the old ballast in order to raise the track. Depending on the depth of the ballast added, this serves to eliminate the existing vegetation by reducing the amount of light it receives. Some vegetation is able to grow up through the ballast and resprout on the new ballast surface.

Geotextiles

The addition of geotextiles underneath the ballast area helps to control plant growth and maintains the integrity of the ballast by stopping the movement of fine soil particles that tend to move up through the ballast from below; water can pass through the semipermeable membrane but soil particles are unable to. Ballast with few fine particles holds less moisture thus is less attractive for plant growth. In Boston, geotextiles were used as a part of Amtrack's Northeast Corridor Improvement Project in order to accommodate heavy loads in an area with an organic clay subbase and a high water table (Lacey and Pannee, 1987). In some undercutting operations, a geotextile can be added as an additional step in the process while using the same equipment and maintaining relatively the same productivity.

Asphalt Ballast

Another option to limit the amount of vegetation that is able to grow in the right-of-way is to apply hot-mix asphalt on the ballast area. This procedure of asphalt application was first used in 1968 by the Cleveland Transit Authority who experimented with two 1,00 foot test sections. The Santa Fe Railway also applied some test sections in 1969 that were 700 feet long. In both cases the layer of asphalt was 2.5 to 7.5 inches thick, and the primary purpose of the tests were to determine if asphalt would add additional strength to the track structure. Testing for this procedure was resumed in 1981 by the University of Kentucky. There are now over thirty different installations of hot-mix asphalt in place (Huang, et al., 1986).

To place an asphalt layer on the track bed the track must first be removed and the underlying ballast excavated to the desired elevation. Experimental techniques have been developed where the track is lifted without removal and a layer of asphalt is placed beneath it (Rose, 1989). Once the asphalt mat and track structure is in place, ballast is spread between the ties and on the shoulders to prevent the ties from slipping on the asphalt (Huang, et al., 1986). In conventional track bed asphalting, the asphalt mat is placed by a standard highway asphalt paver and compacted, and the track is replaced or built on the asphalt or a layer of ballast between the ties and the asphalt. The procedure is referred to as an overlay when the ties are placed directly on the asphalt, and an underlay when there is ballast between the ties and the asphalt (Rose, 1989). Typical hot mix asphalt cross sections are shown in Figure 3 below.

Experimental sections tested with this procedure have proven to be excellent in keeping water from entering into the ballast, and have consistently been drier than similar non-asphalted sections (Huang, et al., 1986). The cost for asphalting the ballast area make it prohibitive for use exclusively as a vegetation control technique, but may be found to provide economic vegetation control of herbaceous and grassy species when used as a means of increasing ballast structural strength.

The most common uses of asphaltic ballast at this time are in areas where developing adequate drainage is costly and raising the track is also expensive. For example, the ballast is often asphalted at the entrances of stations, in tunnels, on platforms, at highway crossings, and on open-floored bridges (Hay, 1982).

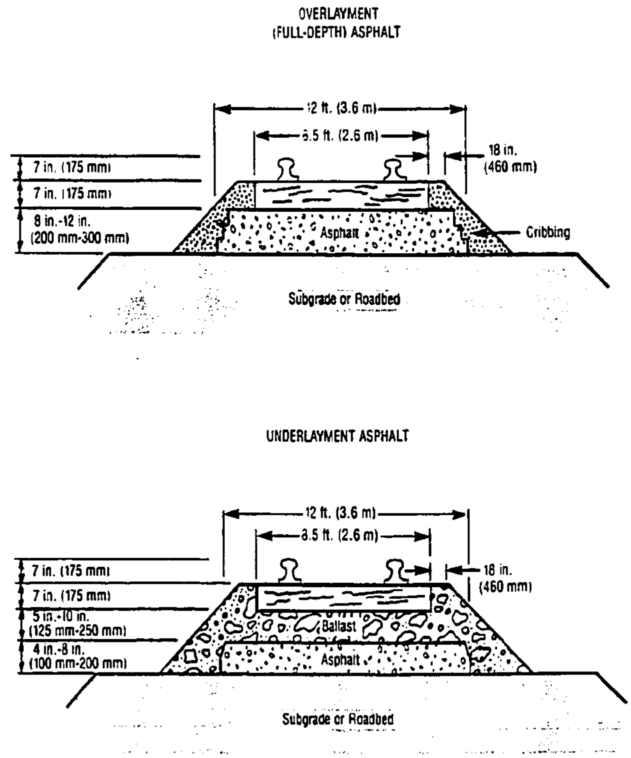


Figure 3: Typical Hot Mix Asphalt Trackbed Cross-Sections. From J.G. Rose, 1989. Use of hma in railroad trackbeds increasing. Hot Mix Asphalt Technology. Page 17.

OTHER METHODS

There are several other methods to control unwanted vegetation. Thermal and biological methods of vegetation control will be discussed in the following sections.

Thermal

One method to eliminate unwanted vegetation is to employ a thermal technique such as burning or steam. In the past, fire was used extensively in crop and railroad applications. Burning is still considered an economic and efficient way to remove undesirable vegetation species in some areas (Swan, et al, 1988), although increased costs of fuel and labor have greatly decreased the use of this method (McWhorter and Chandler, 1982; Archdeacon and Ellsworth, 1985). When weeds are burned as a means of vegetation control, a crew needs to be present to prevent fire from spreading outside the right-of-way. The risk of fire damaging property or getting out of control is relatively high (Archdeacon and Ellsworth, 1985). One objection to burning for weed control is that it contributes to air pollution (Archdeacon and Ellsworth, 1985; AREA, 1988). A permit may be required before burning or burning may be prohibited in some areas (Gangstad, 1982; Hay, 1982). Conversely, some areas require by law that dry vegetation along rights-of way be removed by burning in order to remove the risk of an uncontrolled fire from exhaust or braking sparks from a passing locomotive (AREA, 1988). Optimal use of burning as a means of vegetation control requires several burns in a season to prevent regrowth (Archdeacon and

Ellsworth, 1985). Hand held weed burners or specially equipped trains have been used to burn vegetation.

Another thermal method of controlling vegetation is the use of steam to wilt and kill plants. In comparison with common vegetation control methods, thermal methods seem to be the least used among railroads (AREA, 1988). Steam is not well documented and can be expensive because it is an energy intensive process. Using steam may kill the vegetation but, unlike burning, it leaves the wilted vegetative carcasses along the right-of-way. The dry remains of the dead vegetation are easily ignitable and thus create a potential fire hazard.

Canadian Pacific Rail's British Columbia Division has recently tested the applicability of steam for vegetation control in the ballast area (Smith, 1990). They have found that steam effectively breaks down the plant leaf structure inhibiting photosynthesis. Three days after treatment the plants turn brown and die. The steam apparatus can travel fifteen miles per hour and must contact the plant for at least 1.2 seconds to provide enough energy to kill the plant. This steam technique is to be used this year (1990) on 2,000 miles of track (Smith, 1990).

Biological

Biological control of specific plant species has been practiced for more than a millennium, and has been defined by Harry Scott Smith as the "action of parasites, predators, or pathogens in maintaining other organism's population density at a lower average than would occur in their absence" (Dreistadt, 1989). The classic method of biological control is to introduce predators into an ecosystem and then study the effects. As a safeguard the U.S. Environmental Protection Agency (EPA) has imposed a quarantine procedure that prohibits the import of foreign organisms unless they are believed to be beneficial. To comply with this requirement, the first quarantine facility in the United States was constructed in Hawaii in 1913 (Van den Bosch and Messenger, 1973).

Plant competition and interaction play a key role in biological control methods. Biological control can include the use of a competing vegetation species or natural predators, or the process of selective revegetation, but in most cases the vehicle of the biological control has been an insect (Dreistadt, 1989).

Selective Revegetation

Vegetation competition has been used extensively in agricultural applications, but the same principle can also apply to some areas of railroad right-of-way weed control (Anonymous, 1987c). If undesired woody and herbaceous species are controlled and natural grasses are left unharmed, then the grasses are able to move into areas where weeds formerly existed because there is no longer competition for light, water and soil nutrients (Anonymous, 1987a). This is a complicated process and a great many factors are involved in the establishment of a vegetation species. There may be shallow topsoil, acidic or sandy soils, low natural fertility, or the presence of rocks and boulders that can inhibit establishment of vegetation (Zak, 1983).

Railroads in the past often used herbicides to eliminate all vegetation instead of leaving some selected plant species, or eliminating only woody vegetation and leaving herbaceous vegetation. However, some vegetation can be beneficial when left in the outer right-of-way, beyond the roadbed, where a low growing species of vegetation may serve to provide a groundcover that prevents erosion (Anonymous, 1987c) and absorbs moisture that would otherwise enter into the roadbed area (Hay, 1982).

Native grasses may be used to give effective and economic weed and shrub control (Anonymous, 1987c). Habco Incorporated, a vegetation control contractor, has used Bermudagrass, a low-growing, spreading grass species as a preferred ground cover. They have found that on Mopac Railroad's Western District which includes Kansas, Nebraska, Colorado, and parts of Missouri and Oklahoma, the grass is an effective cover and inhibits weed infestation while reducing mowing and maintenance costs (Anonymous, 1984c). In Massachusetts during 1983 a mixture of common grasses was used on bare highway embankments to improve slope stability and reduce erosion. The highway department used a mixture of creeping red fescue (Festuca rubra), hard fescue (F. elatior var. arundinacea), domestic ryegrass (Lolium spp.), and white clover (Trifolium repens) on the slopes, and found that they were successful in creating an adequate, weed free embankment cover (Zak, 1983).

Five test plot sites were developed in Multnomah County Oregon in 1985 to study IVM methods (De Chant, 1987). A broad range of ecosystems were chosen, and the goal was to establish stable low growing plant communities along backslopes and cut banks adjacent to highways. Mechanical means were used for maintenance of the test plots, and herbicides were only used in extreme cases. The testers selectively removed unwanted vegetation species and then reseeded with a clover mixture. They found that selected removal of problem species was far superior to complete removal of all vegetation (De Chant, 1987).

Some railroads use competitive weed control in conjunction with other methods. Union Pacific uses natural competition on their right-of-way outside the roadbed in the Midwest as a key factor in their vegetation control program for that area, while employing other options elsewhere. The railroad has found that once grasses are established they will form a dense mat and effectively inhibit weed growth (Anonymous, 1987c). There is a specific stage of plant growth, when the plant has expended most of its energy in the growth process and has little stored reserves, when weed control will allow competing vegetation to take over and limit future weed growth in that area (Radosevich, et al., 1984).

Vegetation removal or maintenance equipment if allowed to expose mineral soil in the right-of-way enables weeds to take hold in the uncovered ground. The process of selective revegetation by seeding after completing a project is beneficial, as it keeps weeds at bay and also helps to maintain slope stability. Sodding is sometimes used to provide immediate protection for fine grained soils against erosion. This practice is more expensive than seeding and is usually done when appearance as well as stability is the goal (Hay, 1982). The price for seeding and fertilizing is a small percentage of the total project cost and is a justifiable extra expenditure. By using vegetation competition both short and long term costs are reduced and the right-of-way is improved aesthetically. The practice of removing all vegetation in the right-of-way is now regarded as an uneconomical solution to vegetation control problems (Anonymous, 1987c).

Cultivating a species of low vegetation, probably herbaceous, may be better than completely removing all vegetation outside of the ballast area. If low-growing vegetation were capable of effectively competing with trees and shrubs to reduce their numbers in the right-of-way, then this vegetation would definitely be an asset. Additional money is required to established "good" vegetation but the extra expenditure is compensated for in future decreased vegetation control budgets (Anonymous, 1987c).

Natural Predators

Weeds can also be controlled by introducing natural predators such as insects. The principle of introducing an insect to control a plant species is parallel to that of using an insect to eliminate another insect population. The most difficult part in this interaction is to find an insect that will feed upon and not stray from the intended plant population and damage other plants, such as those outside of the right-of-way. This requires careful testing (Van den Bosch and Messenger, 1973). Extensive studies have been done on insect and plant species interaction to determine which insects are effective for control of certain plant species (Julien, 1982). This type of weed control is most feasible when the aim is to eliminate a concentrated population of one specific plant species (McWhorter and Chandler, 1982). For example, certain weed species have been successfully controlled with the introduction of a population of beetles (Batra, 1981).

Plant Species Interaction

Plants may produce compounds that influence other organisms around them by releasing metabolic by-products into the environment. These allelochemic interactions are selectively toxic to certain animals and plants (Barbour, et al., 1980). In the nonscientific community these natural inhibitors are termed bioherbicides. Scientists previously assumed that the only way plants inhibit other plant species was by shading them, by root competition, and by competing for available soil nutrients and moisture. An actual "chemical warfare" has been detected between plant species (Anonymous, 1985a).

Allelopathy is the direct or indirect harmful effect of one plant on another plant species. Unlike competition, allelopathy is the addition of a substance to the environment rather than the depletion of needed resources to inhibit another plant species (Rice, 1984). It is theorized that allelopathic substances evolved as defenses against animals, bacteria, and fungi, and the effect on other plants is only a side effect. These chemicals occur irregularly, are present in some plant species and not others, and may be in the form of phenolic, terpenoid, or alkaloid compounds (Whittaker, 1975).

Shrubs have been observed to use allelochemical effects to inhibit the growth of other plant species. The release of these substances have created communities of a single shrub species with soil chemistry that other species find uninhabitable (Whittaker, 1975; Barbour, et al., 1980).

Biological control of weeds may become a larger part of weed control as genetic engineering technology advances during the next ten to fifteen years and new biological control methods are developed to eliminate specific weeds (Riggleman, 1986). Biological means to control unwanted plant species should not be regarded as a solution to vegetation control problems that will eliminate the use of herbicides, but rather as another tool to be used in conjunction with chemicals to reduce herbicide use (Hill, 1982). Increased social and economic pressures to reduce chemical dependency have emphasized the need for safe and effective vegetation control alternatives (Dreistadt, 1989). Vegetation control is difficult without herbicides because there are few alternatives to rely on if the non-chemical method fails to adequately control unwanted vegetation (DeVault, 1987). Not all of society supports the reduction of herbicide use however, and in some areas there is a firm belief that herbicides alone present the ultimate vegetation control solution. (Klor and Klor, 1987).

Table 2: Summary of Vegetation Control Methods

METHOD: <u>Chemical, Herbicide Application</u>
- ADVANTAGES:
  - Efficient vegetation removal
  - Many programs already in place
- DISADVANTAGES:
  - Public Opposition
  - Potential for environmental harm

METHOD: <u>Chemical, Non-Herbicide Chemical Application</u>
- ADVANTAGES:
  - Materials readily available
- DISADVANTAGES:
  - May not be effective
  - Expensive
  - Potential environmental problems at effective dosage rates

METHOD: <u>Physical, Mowing and Brush Cutting</u>
- ADVANTAGES:
  - Leaves aesthetically pleasing right-of-way
- DISADVANTAGES:
  - Labor intensive
  - May require more than one treatment per year

METHOD: <u>Physical, Bulldozers and Scraping Equipment</u>
- ADVANTAGES:
  - Removes all vegetation
- DISADVANTAGES:
  - May cause erosion problems in outer right-of-way if not reseeded
  - Labor intensive

METHOD: Physical, Hand Clearing
ADVANTAGES:
Selected plant species easily removed
Vegetation can be removed between ties of track
DISADVANTAGES:
Potential safety problem for crew on tracks
Very labor intensive
May require large crew to cover enough area
May not remove enough of the plant root system to prevent regrowth

METHOD: Physical, Undercutting
ADVANTAGES:
Benefits other than vegetation control
DISADVANTAGES:
Requires a certain maintenance level to be efficient
Equipment may not be readily available

METHOD: Physical, Ballast Regulator
ADVANTAGES:
Benefits other than vegetation control
DISADVANTAGES:
Equipment may not be readily available
May waste ballast

METHOD: Thermal, Burning Vegetation
ADVANTAGES:
Complete removal of vegetation
Lessons fire hazards
DISADVANTAGES:
Causes air pollution
Potential to get out of control

METHOD: Biological Control
ADVANTAGES:
Established cultures fluctuate in population as needed to control vegetation
DISADVANTAGES:
Requires trained professional to develop program
May be difficult to establish an effective program
Potential to harm desirable vegetation

CHAPTER 4

RAILROAD SURVEY

A survey was sent to a number of railroads to determine what methods of vegetation control have been used and are in use on railroad rights-of-way This chapter contains a description of the survey recipients and the contents and results of the survey. Obtaining cost data for vegetation control methods was a secondary objective of the survey. The data obtained are presented in the following sections and analyzed in Chapter 6 for comparison to an independent cost estimate presented in Chapter 5.

SURVEY RECIPIENTS

A survey was mailed during May of 1989 to 174 railroads in the United States and Canada. The railroads selected to participate in the survey were obtained from the Pocket List of Railroad Officials (Todor, 1988) for freight and passenger railroads. All railroads listed with 50 miles or more of track were contacted. After the original survey form was mailed, a second form was distributed in an attempt to increase the response rate of the railroads. To determine what methods other countries were practicing for vegetation control, the survey was sent to a selected group of railroads in foreign countries. A list of all railroads contacted is located in Appendix B.

A numbering system was devised to identify each railroad in order to maintain the anonymity of the survey respondents. Specific railroads may be referred to by name, but in general the brand of herbicide used and the use of other vegetation control methods will remain anonymous in order to respect the confidentiality of the participants. The completed survey forms will be archived in the Environmental Quality Engineering and Science Program, Department of Civil Engineering at the University of Alaska in Fairbanks Alaska.

One hundred six and railroads responded to the survey, which is a response rate of 60 percent. Five of the responding railroads indicated that they were no longer in operation or otherwise unable to answer the survey.

DESCRIPTION OF SURVEY

The initial survey form (a copy is included in Appendix A) requested a description of the vegetation management control methodology of the railroad in both the roadbed and the wider right-of-way. The use of herbicides, their application rates, costs, and application times were also requested along with a description of the costs and techniques for mechanical, thermal/burning, and other methods used to eliminate vegetation along the right-of-way.

Vegetation management reports and cost effectiveness data of vegetation control methods were also requested.

The second survey form (included in Appendix A) requested information similar to the first form, but was greatly condensed. Every participant that did not return a response to the first form by a designated time was mailed a second "short form" survey. The focus of this second request was to determine if methods other than herbicides were used for right-of-way vegetation management.

SUMMARY OF VEGETATION CONTROL METHODS

A summary of the railroad survey responses was compiled in order to analyze the data, and that list is located in Appendix C.

Chemical Methods

Ninety-four percent of the railroads responding to the survey percent, use herbicides in their vegetation control programs. In fact, only seven (which is six percent) of the railroads stated that they currently did not use herbicides. The types of herbicide(s) used to control vegetation varied widely. Most of the railroads did not restrict themselves to one particular herbicide but rather used several products simultaneously. The herbicides most commonly used were Roundup, Arsenal, and Oust. The application zone varied from 14 to 62 feet in width, and the most common application widths were 16 and 24 feet. Eleven percent of the herbicide users reported application widths of 16 feet, seven percent reported application widths of 24 feet, ten percent reported a variety of other widths, and 72 percent did not specify the herbicide application width.

The use of both spray trains and hi-rail vehicles for herbicide application were reported. One railroad indicated that their program used both spray train and hi-rail herbicide application vehicles. Herbicide holding tank sizes of 500 gallons, 1,000 gallons, 1,300 gallons, and 1,500 to 2,000 gallons were described by railroads.

Contractor labor was more popular than internal labor forces for herbicide application. Twenty-three percent of the railroads reported contractor labor usage while four percent used internal labor forces. Two percent of the herbicide users used both contractor and in-house labor and 71 percent did not specify the type of labor used. One railroad stated that they contracted out their vegetation control program on a yearly basis without specifying the form of vegetation control. They found that herbicides were generally used in the ballast area with a combination of herbicides and mechanical methods used on the wider right-of-way.

One railroad reported that their vegetation control program consisted of both pre- and post-emergence herbicide application. Pellet herbicide applications were also described for spot treatment of vegetation. Several railroads use soil sterilization for their herbicide programs while another railroad uses selective herbicides in order to leave the grasses intact. The use of both residual and translocated herbicides were reported. One railroad stated that it did not use any herbicides because it was located in a desert area where vegetation was not a problem. One disadvantage of herbicide usage reported was that herbicides only effect visible vegetation and are unable to destroy plant seeds.

Yearly application was the most popular application frequency reported by the railroads. Several railroads have programs with herbicide application every three to four years and one railroad reported that application was necessary twice yearly.

Physical Vegetation Control Methods

Most railroads (85 percent) reported using another form of vegetation control in conjunction with herbicides. Physical methods such as mowing and brush cutting were common control strategies. Mechanical cutting and mowing are usually used in the wider right-of-way and not in the ballast area. Twelve percent of the railroads reported that they mowed their rights-of-way for vegetation control. Of the railroads that mow, 25 percent use off-track equipment, eight percent use on-track equipment, and 67 percent did not specify. Two percent of the railroads use contractor labor for mowing operations. Several railroads mow twice yearly while one railroad stated that it mowed every three years.

Brush cutting was a popular vegetation control option with 50 percent of the railroads stating they used some form of mechanical brush control. Similar to mowing, this is usually done in the wider right-of-way unless shrubs have been allowed to encroach the roadbed because of poor maintenance. One railroad reported brush cutting operations starting 12 to 14 feet from the track centerline outside of the area covered by their herbicide program.

Of the railroads that reported brush cutter usage, 30 percent use on-track models, four percent use off-track models, 14 percent use both, and 52 percent did not specify which type they use. Four percent of the railroads reported that they lease their brush cutting equipment. One railroad responded that brush was cut on a yearly basis while another said that they cut brush in three to four year cycles.

Hand clearing of vegetation was reported by 32 percent of the railroads. Hand held "weedeaters" and chainsaws are used for spot applications of vegetation control. Thirteen percent of the railroads responding said they used laborers with chainsaws and nine percent said they used laborers with weedeaters. Large trees are also eliminated with chainsaws to facilitate shrub removal with brush cutting machinery.

Hand pulling of weeds was reported by one railroad as a method of vegetation control. Another railroad stated that it used hand clearing in conjunction with plowing, discing, and grading in order to remove all vegetation in areas of high fire hazard. Several railroads use convict labor for hand clearing programs, and one railroad uses a government funded youth corps with hand tools. The productivity for hand clearing was listed by one railroad as eight man-days per mile. It is likely that this productivity is for clearing trees and shrubs with power hand tools, which is commonly done, and not for eliminating all vegetation by hand weeding. Another railroad reported that a track gang for hand clearing one acre costs twice as much as herbicide application on the acre and takes ten times the amount of time.

The use of a ballast regulator for vegetation control was reported by 25 percent of the railroads. A number of the railroads pointed out that vegetation control was not the primary use of the ballast regulator. Ballast regulators were reported to be used during ballasting, surfacing, and track dressing operations or during tie renewal and track maintenance operations to churn up the vegetation.

Several railroads testified that the ballast regulator controls vegetation adequately on the shoulders while others pointed out that it is not effective in the area between the rails. A few railroads reported using the broom attachment on the ballast regulator to beat down vegetation between the rails. One railroad stated that the ballast regulator only pushes down 50 percent of the vegetation when used. A ballast regulator is used by another railroad to clear small trees and vegetation by pulling ballast back into the track structure.

Ditchers, dozers and spreaders are used for vegetation control by 14 percent of the railroads. One railroad reported that ballast regulators, undercutters, spreaders, and ditchers together unintentionally provide 15 to 30 percent of their total yearly vegetation control.

Other Vegetation Control Methods

Burning vegetation along rights-of-way was used in ten percent of the railroads to control vegetation, and in Virginia it is required by state law. Canadian Pacific LTD. is experimenting with steam to control vegetation on their right-of-way.

One railroad plants grass after their construction projects in order to develop a low vegetation cover. Another railroad is developing competing vegetation techniques to inhibit undesirable vegetation growth. Geotextiles are routinely used by one railroad in reconstruction projects to inhibit vegetation growth. Table 3 and Figures 4 and 5 summarize the methods of vegetation control used by the participating railroads.

Table 3: Summary of Vegetation Control Methods Used by Survey Respondents

Herbicide Use	93%
Contractor Labor	23%
In-house Labor	4%
Both Types Labor	2%
Unspecified Labor	71%
No Herbicide Use	7%
Physical Methods	85%
Mowing	12%
On-track Equipment	8%
Off-track Equipment	25%
Unspecified Equipment	67%
Contract Labor	2%
Unspecified Labor	98%
Brush Cutting	50%
On-track Equipment	30%
Off-track Equipment	4%
Both Types Equipment	14%
Unspecified Equipment	52%
Leased Equipment	4%
Ballast Regulator	25%
Hand Clearing	32%
Chainsaw Use	13%
Weedeater Use	9%
Ditcher, Dozer or Spreader	14%

The top pie graph (Herbicide Usage) in Figure 4 represents the percentage of railroads, from the survey, that use herbicides for vegetation control. The bottom pie graph (Other Vegetation Control Methods) depicts the percentage of railroads that use other forms of vegetation control excluding herbicides. The vegetation control methods shown in Figure 4 are not mutually exclusive. For example, a railroad may use herbicides, mowing, and brush cutting simultaneously to control vegetation on their right-of-way. The values shown for a method of vegetation control, when Figure 4 (the pie depicting Other Vegetation Control Methods) is compared to Figure 5, are different. This difference is caused by the fact that railroads use more than one method of vegetation control. In Figures 4 and 5 if the total percentage of the vegetation control methods were added the sum would be more than 100 percent because the methods are not mutually exclusive. The graph in Figure 4 proportionalizes the values so they can be represented in a pie form.

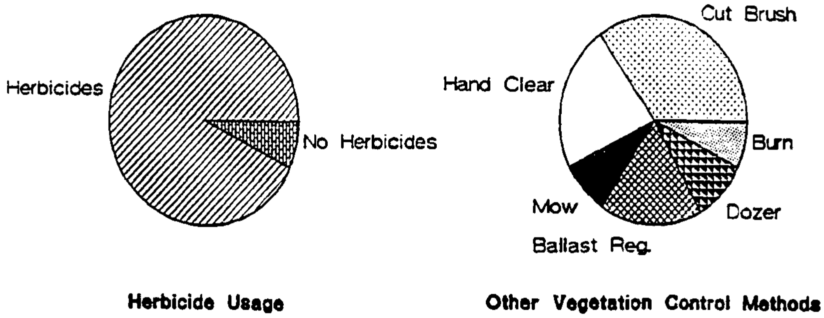


Figure 4: Railroad Vegetation Control. 1989 Survey Results

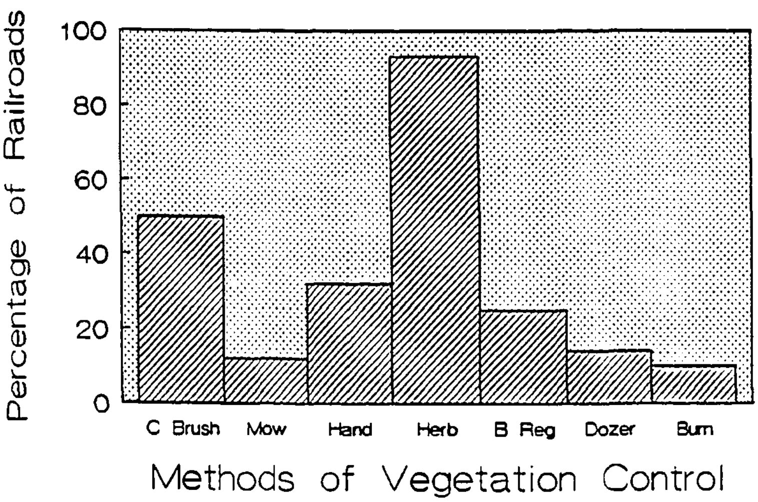


Figure 5: Vegetation Control Methods. 1989 Survey Results

ANALYSIS OF REPORTED VEGETATION CONTROL COSTS

The following sections contain a summary of the cost information obtained from railroads participating in the survey. A description of how the data were compared is also included.

Geographic City Cost Conversion

In order to compare information that was gathered in different states and areas of the country, the data were converted to average United States city values. This was accomplished by using conversion factors found in City Cost Indexes from the Means Building Construction Cost Data text (Mahoney, 1988). The construction indexes reflect the cost of construction projects for a variety of trades, including wages, materials, and equipment, in 30 major cities in the United States. These cities are used to develop an average data base, which equals 100 points, and other cities are compared to this value. If a city has an index value greater than 100, construction projects in that area cost more than the national average. If the index value is less than 100, the cost of construction is less than the national average. Selected Canadian cities are included in the index so they can be compared to U.S. cities. When Canadian conversions were done, an exchange rate of $1.00 Canadian to $.80 American was used.

The cost indexes can be used to convert data from a particular city to a national average value, or to convert data from one city to another. To convert data from one city to another a ratio of the city indexes for the two cities is multiplied by the value to be converted. Table 4 demonstrates a sample calculation for converting a city cost to a national average cost.

To convert the cost data reported by the different railroads to a common data base, a base city was established for each railroad. The selection of a base city for conversion was difficult as most of the railroads covered more than one state. The city from where the data were reported was chosen as the base city because, in most cases, it is the railroad's headquarters and thus most of their business transactions are based out of that city. In some cases, that city was not on the data base, so a city of similar size in the same state was used instead.

Table 4: Sample Calculation of Cost Conversion for Changes in Geographic Location

Given: Omaha, Nebraska Index = 90.2
Cost of Project = $1,000
Find: Cost of the Project in an Average U.S. City

Calculation: National Average Cost =
(Cost in Omaha) * 100/(Omaha City Index)
National Average Cost = ($1,000) * 100/(90.2)

National Average Cost = $1,110

Costs Reported From Survey

The cost data obtained by the survey are analyzed and presented in the following paragraphs. An independent estimate of the costs for vegetation control methods was performed in Chapter 5, in order to verify the cost data reported from the surveys. The costs from the survey recipients are reported, as gathered, in 1989 dollar base. All the costs in the following sections have been converted to an average U.S. city dollar base. In Chapter 6 the survey data will be converted to a 1991 dollar base and compared to the independent estimate calculated in Chapter 5.

A variety of vegetation control methods are applicable to the roadbed area and also the wider right-of-way. For the data obtained by the survey, the roadbed area will be considered because this is the area where vegetation control is most crucial. Efficient railroad operation is influenced by the adequacy of vegetation control in the roadbed. The independent cost estimate that follows in Chapter 5 also focuses on vegetation control in the roadbed area.

Basic Assumptions

Some basic assumptions were made when considering the cost data reported by the railroads. It was assumed that the prices reported were comparable to those incurred by a contractor. For example, the costs included the amortized cost of the equipment, maintenance and operation costs for equipment, and wages and benefits for the workers.

Chemical Methods

The data from the survey responses were compared on a per mile basis and then converted to a cost per acre figure so that different herbicide spray widths could be accounted for. The cost of the herbicide treatment program varied from railroad to railroad. The data given by the railroads were converted to national average values, as discussed previously, and to an Anchorage, Alaska data base for comparison. Seventeen railroads submitted herbicide application cost data, and the cost per mile (Average U.S. City Costs, 1989 Dollar Base) ranged from $57 to $1,130, with an average value of $188 per mile. The per acre spray costs ranged from a low of $15 to a high of $454 with a median value of $74. Table 5 is a summary of the herbicide cost data showing the railroad identification number, the city and state where the headquarters of the railroad is located, and the per mile herbicide application cost. Some railroads reported more than one cost to apply chemicals. This reflected the fact that different chemicals are used in the spray program and/or the herbicide application zone may vary with the application area. For example, the railroad may have one program for applying herbicides to dual railroad lines or in the rail yard, and another program for single mainline track.

The railroad that reported a $1,130 per mile herbicide application cost was well above the range of the other costs reported. Two cost values per mile reported, $7.80 and $4.50, were excluded from the analysis as they were obviously much lower than the other data, and probably only included chemical costs and not equipment and labor costs. One railroad had a wide range between the two herbicide application costs reported ($63.40 per mile to $179 per mile). This range can be attributed to their two different herbicide application programs and the differing costs between the chemicals. The herbicide costs reported were split into three ranges. The average per mile low-range application cost was $95, the average mid-range per mile application cost was $195, and the average high-range per mile application cost (excluding the $1,130 per mile value) was $340. Further discussion on the variability of the data reported will be discussed later in the chapter.

Physical Methods

Several physical methods of vegetation control were reported by railroads, including brush cutting, using the ballast regulator, and hand clearing.

Table 5: Herbicide Cost Data. Reported in 1989 Dollar Base

Railroad Id #	State City	As-Reported Local Cost	Average U.S. City Cost	Anchorage Cost
5	FL Jacksonville	$75/mi $100/mi	$86/mi $115/mi	$108/mi $145/mi
11	AL Montgomery	$153/mi	$131/mi	$238/mi
14	Canada Vancouver	$288/mi $283/mi	$265/mi $261/mi	$322/mi $329/mi
15	PA Pittsburgh	$88/mi $120/mi	$87/mi $119/mi	$114/mi $156/mi
18	FL Jacksonville	$200/mi $250/mi	$229/mi $287/mi	$300/mi $376/mi
20	IL Chicago	$130/mi	$128/mi	$161/mi
24	Canada Quebec	$1,100/mi	$1,130/mi	$1,420/mi
28	ID Boise	$53.6/mi $58.9/mi	$56.7/mi $62.2/mi	$71.5/mi $78.4/mi
41	Canada Winnipeg	$320/mi	$317/mi	$400/mi
49	IA Des Moines	$287/mi	$315/mi	$413/mi
56	MS Jackson	$291/mi $335/mi $339/mi	$349/mi $402/mi $407/mi	$458/mi $527/mi $458/mi
62	LA New Orleans	$191/mi	$213/mi	$269/mi
63	VA Norfolk	$100/mi	$119/mi	$156/mi
92	NE Omaha	$72.5/mi $75/mi	$80.4/mi $83.1/mi	$105/mi $109/mi
93	Pa Pittsburgh	$88/mi $102/mi	$87/mi $101/mi	$115/mi $133/mi
95	WI Milwaukee	$61.4/mi $173/mi	$63.4/mi $179/mi	$83.2/mi $235/mi
99	WA Tacoma	$150/mi $200/mi	$145/mi $193/mi	$190/mi $254/mi

Brush Cutting

Brush cutting is a vegetation control option practiced in both the inner and outer rights-of-way. On-track brush cutters were the most popular, but not all of the railroads specified which type of brush cutter they had when reporting cost data.

The per mile reported costs for brush cutting (Average U.S. City Values, 1989 Dollar Base) ranged from $21.50 to $1,940. The per mile value of $21.50 was well outside the range of the other data reported, and the average per mile value excluding that point was $720. Variances in the reported costs will be discussed later in this chapter. Table 6 shows the reported costs for brush cutting.

Table 6: Brush Cutting Cost Data. Reported in 1989 Dollar Base

Railroad Id #	State City	As-Reported Local Cost	Average U.S. City Cost	Anchorage Cost
14	Canada Vancouver	$200/mi	$230/mi	$302/mi
20	IL Chicago	$200/mi	$197/mi	$258/mi
18	FL Jacksonville	$1,000/mi	$1,150/mi	$1,500/mi
56	MS Jackson	$327/mi	$393/mi	$515/mi
92	NE Omaha	$1,750/mi	$1,940/mi	$2,250/mi
96	WI Madison	$20/mi	$21.5/mi	$28.2/mi
77	NY Rochester	$420/mi	$414/mi	$543/mi

Ballast Regulator

A ballast regulator is used in some instances to control vegetation in the ballast area. The regulator accomplishes this by scraping away the vegetation with blades or wings that extend from the sides of the machine. A number of railroads reported cost data on this method of vegetation control, but most were quick to point out that ballast regulating is not commonly used for vegetation control but normally for track maintenance operations.

The cost of ballast regulating (Average U.S. City Values, 1989 Dollar Base) ranged from $49.70 per mile to $317 per mile with an average of $219/mile. A summary of the cost data reported from the survey is included as Table 7.

Table 7: Ballast Regulator Cost Data. Reported in 1989 Dollar Base

Railroad Id #	State City	As-Reported Local Cost	Average U.S. City Cost	Anchorage Cost
28	ID Boise	$47/mi	$49.7/mi	$65.2/mi
41	Canada Winnipeg	$320/mi	$317/mi	$400/mi
56	MS Jackson	$242/mi	$291/mi	$381/mi

Hand Clearing and Burning

Thirty-two percent of the railroads responding to the survey reported that some form of hand clearing to control vegetation is used. It was unclear whether this vegetation control is done in the roadbed area or in the wider right-of-way. From the survey responses the most common form of vegetation control by hand clearing is the use of a chain saw to eliminate large trees in the right-of-way, which is practiced by 13 percent of the railroads. One railroad reported a hand clearing cost of $1,030 per acre which is $2,490 per mile when a 20-foot width is considered. The other railroads reported costs of $1,720 and $2,870 per mile for their hand clearing programs without specifying a width of treatment.

Only one railroad reported a cost for burning their right-of-way, and this method of vegetation control seemed to be unpopular. The reported cost was $1,110 per mile to burn the right-of-way, and no treatment width was specified.

INTREPRETATION OF DATA

The data reported by the railroads vary greatly for each method of vegetation control. Although some of the variations are no doubt due to varying work efficiencies, field conditions, equipment productivity and the like, it is also likely that not all railroads reported total costs in their survey responses. For example, some railroads may be reporting only the labor and fuel costs of an operation while another may be including the amortized equipment cost and maintenance costs. When contractor prices are reported, markup or profit is included in the figure. When a railroad reports its internal cost for performing an operation, no profit margin is included.

An independent analysis of the cost for a variety of vegetation control operations is included in the next chapter. These independent cost calculations will be compared in Chapter 6 to the data obtained from the railroad survey as described in the present chapter.

CHAPTER 5

INDEPENDENT COST ESTIMATE

INTRODUCTION

To supplement the cost data that were received from railroads participating in the survey, an independent cost estimate was developed for each method of vegetation control applicable in the ballast area. Data were obtained through a review of the pertinent literature and by personal communications. When possible estimates were prepared using a range of data to account for varying conditions.

Each estimate is divided into equipment costs (including maintenance and fuel), labor costs (including base pay, benefits, and per diem), mobilization and demobilization costs, overhead and indirect costs, and profit. Materials costs were also included where applicable. The costs are reported in dollars per track mile for a specified width of control.

Dollar Base Conversion

All costs were converted into a 1991 average U.S. city dollar base using the United States Consumer Price Index (CPI-US). The index reflects the price consumers must pay for goods and services as well as their wage rates during a specified year. General economic trends from year to year can be compared in this manner. For the CPI-US index (Dole,

1990) the baseline was developed by averaging the indexes from the years 1982 to 1984 and making this value 100. The yearly index values were graphed and the 1991 index was estimated by straight-line extrapolation. Limitations exist with this method because the index value in 1991 is based on a predicted value, if large economic changes happen within a short period of time the predicted cost may vary from the actual cost. Figure 6 shows a graph of the index values. A sample calculation of the conversion from one year to another is included as Table 8.

Table 8 : Sample Calculation of CPI-US Conversion

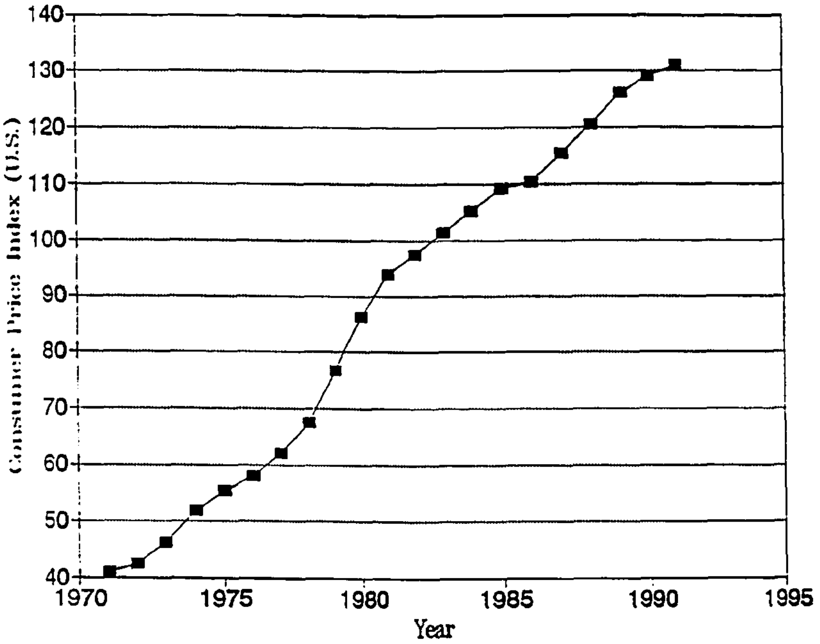
Given: Purchase price in 1977 = $50,000
Find: Price of item in 1991

Calculation: CPI-US for 1977 is 62.1
CPI-US for 1991 is estimated at 131

Price in 1991 =
(CPI-US for 1991/CPI-US for 1977) * Price in 1977

Price in 1991 = (131/62.1) * $50,000
Price in 1991 = $105,000

To distribute the costs over a period of years a conservative interest rate of ten percent was chosen. Interest rates vary, and a rate comparable to the amount railroads would make on their money if invested elsewhere, or the amount they would pay to borrow money was chosen. Burns (1987a) used an eight percent interest rate for economic evaluations, and a ten percent interest rate was used in a 1985 study of vegetation management for the Alaska Railroad Corporation (Tryck, Nyman & Hayes, 1985) The more conservative value of ten percent was chosen for this estimate. If another interest rate was desired, then it could be substituted into the calculations instead of the ten percent interest rate, and a similar method used to determine the costs.



Adapted from Table 3, page 15 of the Historical Price Index for All Urban Consumers (CPI-U) and Urban Wage Earners and Clerical Workers. U.S. city average data based in December of each year. U.S. Department of Labor, E. Dole, Sec. 1990 CPI Detailed Report. 111 pp.

Figure 6: Year Versus U.S. Consumer Price Index, U.S. Average City Data.

A capital recovery factor (A/P) corresponding to the interest rate and service life of the equipment was selected from a standard compound interest table (Grant, et al., 1990) and multiplied by the value. Table 9 shows a sample interest rate calculation for a product with a $50,000 purchase price, a ten year product life, an interest rate of ten percent, and an assumed zero salvage value.

Table 9: Sample Calculation of Yearly Cost

<u>Given</u>: Purchase price = $50,000
Product life = 10 years
Interest Rate = 10%
<u>Find</u>: Yearly cost of that product over its life
<u>Calculation</u>: A/P, 10% for 10 years = 0.16275
Yearly Cost = (A/P, 10%, 10) * Purchase price
Yearly Cost = (0.16275) * ($50,000)
Yearly Cost = $8,140

<u>General Assumptions</u>

A variety of assumptions were made for the estimates, and in most cases they are stated within the appropriate section. Several general assumptions were used in the cost calculations for each method of vegetation control. Standard values for interest rate, overhead, indirect and profit calculations as well as those for the cost of equipment maintenance, mobilization and demobilization are assumed as noted. A standard wage rate table used to determine labor costs is also included as Table 10.

Maintenance Costs

Yearly maintenance costs for most railroad equipment range from 10 to 30 percent of the purchase cost, and for some types of equipment a standard maintenance ratio has been established (Cataldi and Elkaim, 1980). Where this ratio was not available a mid-range value of 20 percent was chosen for this study. This value "suggests that on the average it takes twenty percent of the undepreciated value of work equipment to maintain that equipment for the year" (Cataldi and Elkaim, 1980). It is common that track maintenance (including vegetation control) equipment operates for 150 to 300 shifts per year for railroads operating in the contiguous United States (Cataldi and Elkaim, 1980). When the number of yearly operating shifts for a specific piece of machinery was unknown a value within this range, 200 shifts per year, was chosen.

Labor Costs

United States average daily wage rates for railroad workers of different job classifications were adopted from Cataldi and Elkaim (1980) and used to determine the labor costs for each vegetation control estimate. Table 10 depicts wage rates based on Cataldi and Elkaims's assumptions of an eight hour work day including 41 percent benefits and a fixed value for daily expenses. The wages were modified from a 1980 dollar base to a 1991 dollar base using the CPI-US as demonstrated in the Dollar Base Conversion section. The conversion to 1991 dollar base was accomplished so that the cost data would reflect the year in which it will be used. Another conversion to standardize the data gathered from different cities to national average values can be performed. This conversion was discussed in Chapter 4, and the procedure was used to convert the costs to an Anchorage Alaska data base.

Each vegetation control method employed a different support staff but the wage rates on which the labor cost was based for different labor classifications (laborer, general foreman, etc.) remained constant for all types of operations. The expenses for the different labor classifications are not constant but reflect the fact that higher skilled job classifications receive a higher daily expense allocation. For example, a general foreman has a daily expense allocation of $61 while a laborer's daily expense allocation is $18. (These values are shown in Table 10.) This follows the trend of railroads to pay the upper level individuals more as an incentive for greater productivity.

Table 10: Daily* Wage Rates by Job Classification. Reported in 1991 Dollar Base

Title	Base Pay	Plus 41% Benefits	Expenses	Total U.S. Avg. Labor	Anchorage AK Labor
General Foreman	$161	$226	$61	$287	$475
Track Foreman	$112	$158	$18	$176	$291
Operator Grade 4	$138	$194	$61	$255	$422
Operator Grade 3	$112	$158	$18	$176	$291
Operator Grade 2	$109	$154	$18	$172	$286
Operator Grade 1	$100	$141	$18	$159	$264
Laborer	$95	$134	$18	$153	$254

Adopted from Cataldi and Elkaim, 1980. Page 29, Table 18
* Based on an 8 hour day

Mobilization and Demobilization Costs

Costs are incurred for each project when equipment and personnel are taken to and from a particular job site. In some cases this cost is included in the overhead and indirect project costs, but in others it is calculated separately. For railroad projects mobilization and demobilization may involve considerable expense because of delays associated with other traffic on the rails. An estimate of the cost for mobilization and demobilization was calculated using a report by Tryck, Nyman & Hayes, for the Alaska Railroad in August of 1985 (Tryck, et al., 1985). For each vegetation control alternative considered, the mobilization and demobilization costs estimated in the Tryck, Nyman & Hayes report were compared to the total per mile cost of the method. Mobilization and demobilization ranged from two percent to three percent of the total vegetation control cost in their analyses. To account for the uncertainty of the productivity rates in the Tryck, Nyman & Hayes estimates a conservative value of five percent of the equipment and labor costs was chosen as the mobilization and demobilization estimate for the present study.

Overhead, Indirect Costs, and Profit

Overhead costs are those costs which are not associated directly with any particular work item but are necessary for project completion (Clough, 1986). For example, insurance costs, workers compensation, permit fees, and office expenses such as salaries for a timekeeper, a project manager, and a project engineer are some of the items that may be included in overhead expenses.

Indirect costs encompass the daily expenses of running a business, and are not only incurred by a specific project but are shared by all projects within an organization. They may include secretarial support, telephone charges, office supplies, first aid equipment, and many other items. To account for these expenses it is common to increase the project cost by a fixed percentage.

The profit or markup taken on a job, in some instances, is included with the overhead and indirect costs. The amount of profit varies from job to job and depends on the existing market conditions and the desirability of the job. Engelsman's General Construction Cost Guide (Engelsman, 1985) states that the overhead, indirect and profit on construction projects range from 20 to 40 percent of the total project cost. Godfrey (1974) suggests that 25 percent is a reasonable figure for overhead, indirect and profit. Currently, the Fairbanks North Star Borough (Fairbanks, Alaska) allows a ten percent overhead and indirect, and a 15 percent profit markup for all of their change orders on construction projects. It was assumed that railroad projects are similar to other types of construction projects, and an overhead and indirect cost of 10 percent and a profit of 15 percent (totaling approximately 25 percent) of the total project costs was chosen.

Table 11 summarizes the general assumptions. For items with a range of values, an average value was chosen when specific data was unavailable.

Table 11: Summary of General Assumptions

Item	Value
Interest Rate	10%
Maintenance	10-30% first cost
Operation	150-300 shifts/year
Labor	8 hour workday
Benefits	41% of base pay
Overhead & Indirect	10%
Profit	15%
Mobilization & Demob.	5% of equipment & labor

COST ESTIMATES

Estimates were compiled for herbicide application, brush cutting operations, ballast regulator use, reballasting, undercutting operations, and hand weeding.

Herbicide Application Costs

Herbicides are applied in the ballast area for this form of vegetation control, using a herbicide spray unit. Herbicide sprayers are able to reach a variety of widths on each side of the track centerline, but twenty feet is the most common (Anonymous, 1989). Field tests that were done in conjunction with this study (Mulkey, 1990) used a herbicide application width of 24 feet.

A variety of factors influence the cost of applying herbicides to control vegetation. Some of these items are the chemical cost, equipment and fuel cost, labor cost, mobilization and demobilization cost, spill cleanup equipment cost, profit, indirect costs, and overhead costs.

Herbicides are normally applied at rates of 50 to 80 gallons per acre (Caswell, et al., 1981-1982), and the application equipment may have a tank that ranges in size from 1,000 to 10,000 gallons in capacity (Holt and Osburn, 1985; Anonymous, 1986c). Herbicide application productivity has been recorded from one source as 200 miles in three days (67 miles per day) of dual treatment of the track (Anonymous, 1986c) and as 33 miles per day (Sheahan, 1988) from another source. The reason for the variability in productivity is unclear but may be due to differing herbicide tank holding capacities.

Equipment Costs

It is assumed that herbicide application equipment is devoted solely to applying herbicides and it is not used for other tasks. Application systems vary in tank capacity, and this variance influences the efficiency. Small tanks (about 1,000 gallons in capacity) are sometimes used, but they require frequent stops to refill with water and chemicals. Larger systems can have the capacity to treat the right-of-way with more than one type of chemical. Very large systems with tank sizes in the 10,000 gallon range exist, but are cost prohibitive in areas where large volumes of herbicide application are not needed.

For the present analysis, a 2,000 gallon capacity dual treatment herbicide applicator was chosen. It has an estimated 1991 (average U.S. city dollar base) purchase cost of roughly $150,000 (Hag, 1990). When a single spray system is considered the cost is less, and for large spray train systems the cost may double. For this exercise, a moderate cost figure was chosen. With an estimated life of ten years, the yearly cost for this equipment, using the capital recovery factor as demonstrated previously and a ten percent interest rate, is $24,400 (average U.S. city, 1991 dollar base).

The yearly maintenance for this machine, as discussed previously, using Cataldi and Elkaim's guidelines is assumed to be 20 percent of the purchase price. The calculated maintenance cost is $30,000 per year. Table 12 demonstrates a sample calculation for maintenance costs.

Table 12: Sample Calculation for Herbicide Maintenance Costs. Average U.S. city values, 1991 dollar base

<u>Given</u>:	Purchase Price = $150,000
	Maintenance Cost is 20% of Purchase Price
<u>Find</u>:	Maintenance Cost per Year
<u>Calculation</u>:	
($150,000/year) * (20%) = $30,000/year	

The fuel cost for this equipment is estimated as $30 per shift (Cataldi and Elkaim, 1980). Translated into a 1991 dollar base using the CPI-US, as demonstrated above, this per shift fuel cost is $46. An average amount of equipment usage based on Cataldi and Elkaim's guidelines of 200 shifts per year is assumed, and the yearly fuel price is $9,110. A sample calculation for the annual fuel cost is demonstrated in Table 13. The yearly herbicide application equipment costs are summarized in Table 14.

Table 13: Sample Calculation for Herbicide Annual Fuel Costs. Average U.S. city values, 1991 dollar base

<u>Given</u>: Fuel Cost per Shift = $46
Equipment Operates 200 Shifts per Year
<u>Find</u>: Yearly Fuel Costs

<u>Calculation</u>:
($46/shift) * (200 shifts/year) = $9,110/year

Table 14: Summary of Annual Herbicide Application Equipment Costs. Average U.S. city values, 1991 dollar base

Amortized Purchase Price	$24,400
Maintenance Costs	$30,000
Fuel Costs	$9,110
TOTAL YEARLY EQUIPMENT COSTS	$63,500

Safety Equipment Costs

When applying chemicals to control vegetation, there is the possibility that a chemical spill may occur. Basic safety equipment should be available to protect workers and to facilitate containment and cleanup operations. For this estimate it is assumed that safety equipment is needed for three additional workers along with the two person crew already with the herbicide apparatus. Equipment to protect the workers such as gloves, coveralls, respirators, goggles, and an eye wash station are included in the cleanup/safety equipment kit, along with shovels and spill absorbent. For this estimate extra amounts, approximately one years use, of disposable worker protection items such as tyvex suits and respirator cartridges were included so they would be available for more than one incident.

Eight rolls of a blanket spill absorbent 150 feet long, 36 inches wide, and $^{1}/_{4}$- inch thick per roll were selected. This is capable of containing a rectangular area 450 feet by 158 feet, or of soaking up a 7,200 square foot area of spilled material. Eighteen cans of a spill absorbent that is capable of containing 55 gallons of water-based liquid per 2.5 gallon can were included in the safety equipment kit. Assuming a 2,000 gallon herbicide tank capacity, the solid spill absorbent is capable of absorbing about 50 percent of the total volume if a full tank was spilled. The amount of cleanup and containment materials is limited by the supply storage capacity on the herbicide application vehicle. Some of the materials may be stored at a location near the herbicide application area for dispatch in case of a spill.

Basic first aid equipment was not included in the estimate, as it was assumed that those items are also needed for other jobs and will be included in the overhead and indirect expenses. Table 15 contains a list of the equipment needed and their associated costs. The price estimates were taken from current (1989) catalogs of Forestry Suppliers, Inc. and Direct Safety Company, who are two of the many suppliers of this type of equipment, and they include freight costs.

The cost of the items were converted to a 1991 dollar base using the CPI-US conversion factor, and the total was $2,460 annually. This cost may vary on a yearly basis as some items may have to be replaced and others can be used for a number of years.

Table 15: Safety and Spill Cleanup Equipment. Average U.S. city data, 1991 dollar base

Eye Wash Station, 16 gallon		$382
Safety Goggles	5 @ $6.50 ea	$33
Respirators	5 @ $16.47 ea	$82
Respirator Cartridges	20 @ $4.93 ea	$99
Tyvex Coveralls w/Boot	Box of 25	$149
Unlined Nitrile Gloves	20 @ $2.10/pair	$42
Shovel	2 @ $18.70 ea	$37
Spill Absorbent Blanket	8 @ $141/roll	$1,128
Spill Absorbent	18 @ $28.20/can	$508
TOTAL FOR SPILL KIT	$2,460	

Labor Costs

A two person crew is assumed for herbicide application with one laborer and one operator (grade 4). The daily cost of labor (average U.S. city values, 1991 dollar base) as shown in Table 10 is $153 for a laborer and $255 for an operator. An average equipment usage of 200 shifts per year, as specified by Cataldi and Elkaim (1980), results in a total yearly labor of $81,600. One shift per day is considered assuming that the labor cost will only be calculated when the equipment is working, and for the remainder of the year personnel will be occupied with other tasks. Table 16 is a sample calculation of the yearly wage calculation.

Table 16: Sample Calculation of Yearly Labor Cost. Average U.S. average city values, 1991 dollar base

<u>Given</u>: Labor Costs of $153 and $255 per Shift
Personnel Work 200 Shifts per Year
<u>Find</u>: Yearly Labor Cost

<u>Calculation</u>:
$153/shift + $255/shift = $408/shift
($408/shift) * (200 shifts/year) = $81,600/year

Chemical Costs

The actual herbicide costs and their transport costs are included in the chemical costs for herbicide application. The transportation cost for the chemicals was not computed directly for this estimate, but rather the cost was considered a function of the productivity of the process. For example, the more times an application unit has to refill, the less acreage of herbicide it is able to apply. Some basic assumptions are made on the application rates of the herbicide and the tank capacity of the chemical application vehicle. The assumption is that all chemicals for one application day can be carried directly on the herbicide application apparatus, and an application rate of 65 gallons per acre, which is in the 50 to 80 gallon range discussed previously, is used. A 2,000 gallon tank capacity is also assumed, and the herbicide application zone is twenty feet as discussed previously.

Chemical cost and the application concentration varies with the particular product. Chemical costs were gathered from Forestry Suppliers (1989) for several types of herbicides. These costs are conservative (high) estimates because they may be bought directly from the chemical company at a lower cost. Table 17 is a summary of these chemical costs.

Table 17: Summary of Herbicide Chemical Costs. Average U.S. city data, 1991 dollar base.

Chemical Name	Quantity	Average U.S.City Cost
Velpar L	30 gallons	$1,750.00
Arsenal	1 quart	$87.25
Garlon 3A	2.5 gallons	$149.00
Tordon	2.5 gallons	$49.95

Each of the herbicides has a different application concentration per acre. The concentration for Velpar is three gallons per acre, for Arsenal four pints per acre, for Garlon 3A seven quarts per acre, and for Tordon one and a half gallons per acre (Bullington, 1987). When the 20 foot (0.00379 miles) width spray zone is considered, the cost per mile for each chemical can be determined. Table 18 demonstrates a sample calculation for the Velpar chemical cost calculation, and Table 19 summarizes the chemical cost per mile for the various chemicals.

Table 18: Sample Calculation for Velpar Chemical Cost. Average U.S. city data, 1991 dollar base

<u>Given</u>: Velpar Chemical Cost = $1,750 for 30 Gallons
Application Concentration = 3 gallons per acre
<u>Find</u>: Chemical Cost for Velpar per Mile

<u>Calculation</u>:
($1,750/30 gallons) * (3 gallons/acre) * (0.00379 miles) * (640 acres/square miles) = $425/mile

Since the chemical costs per mile noted seem to be grouped into two broad cost categories of high and low, chemical costs of $250 per mile and $425 per mile will be used. When these costs are converted to 1991 dollar base, using the CPI-US conversion as demonstrated previously, they become $260 per mile and $442 per mile respectively. The Tordon cost of $182 per mile will not be used for projecting costs. Use of higher values results in a conservative estimate with some margin of error included.

Table 19: Summary of Chemical Costs per Mile. Average U.S. city data, 1991 dollar base

Chemical	Application Concentration	Total
Velpar	3 gallons/acre	$425/mi
Arsenal	4 pints/acre	$423/mi
Garlon 3A	7 quarts/acre	$253/mi
Tordon	1.5 gallons/acre	$182/mi

Cost Conversion to per Mile Basis

For each cost category considered, equipment, labor, and safety costs, the costs can be converted to a per mile basis. The productivity of the vegetation control method must be considered for the per mile conversion. Productivities of 33 miles per day and 67 miles per day will be used with one shift per day, as discussed previously. A sample calculation of the per mile equipment cost, using the 33 mile per day productivity, is included in Table 20 along with Table 21 that summarizes the per mile costs for the other cost categories.

Table 20: Sample Calculation for Equipment Cost per Mile. Average U.S. city data, 1991 dollar base

Given: Yearly Equipment Cost = $63,500
Equipment Utilization = 200 Shifts per Year
Productivity = 33 Miles per Day
Find: Equipment Cost per Mile

Calculation:
($63,500/year) * (shift/33 miles) * (year/200 shifts) = $9.62/mile

Table 21: Summary of Costs for Herbicide Application per Mile. Average U.S. city data, 1991 Dollar Base

Productivity:	67 miles/day	33 miles/day
Equipment	$4.74/mi	$9.62/mi
Safety Equipment	$0.18/mi	$0.37/mi
Labor	$6.09/mi	$12.40/mi
Subtotal Costs	$11.00/mi	$22.40/mi

Mobilization and Demobilization Costs

The amount of time and distance required to get the herbicide application vehicle to the application site (mobilization) influences the overall cost of herbicide application. As previously discussed, the mobilization and demobilization costs are determined by taking five percent of the equipment, labor, and materials costs. When the chemical cost of $260 per mile is considered the total cost per mile ranges from $271 to $283, depending on the productivity rate. For the chemical cost of $442 per mile, the total cost per mile ranges from $453 to $464. A sample calculation for the mobilization and demobilization costs is included as Table 22.

Table 22: Sample Calculation of Mobilization and Demobilization Costs. Average U.S. city data, 1991 dollar base

Given:	Subtotal Costs (Equipment, Safety Equipment, and Labor) = $11 per Mile Chemical Costs = $260 per Mile Mobilization and Demobilization = 5%
Find:	Mobilization and Demobilization Costs

Calculation:
Subtotal cost + Chemical Cost:
($11.00/mile) + ($260/mile) = $271/mile Total Cost

($271/mile) * (5%) = $13.60/mile

A summary of the per mile mobilization and demobilization costs is included as Table 23 for a per mile chemical cost of $260 and Table 24 for a per mile chemical cost of $442.

Table 23: Summary of Mobilization and Demobilization Costs For a Chemical Cost of $260 per Mile. Average U.S. city data, 1991 dollar base

	67 miles/day Productivity	33 miles/day Productivity
Equipment,Safety & Labor	$11/mi	$22/mi
Chemical Cost	$260/mi	$260/mi
Subtotal Costs	$271/mi	$283/mi
Mobilization & Demobilization	$13.6/mi	$14.2/mi
TOTAL COST	$285/mi	$297/mi

Table 24: Summary of Mobilization and Demobilization Costs For a Chemical Cost of $442 per Mile. Average U.S. city data, 1991 dollar base

Equipment,Safety & Labor	$11/mi	$22/mi
Chemical Cost	$442/mi	$442/mi
Subtotal Costs	$453/mi	$464/mi
Mobilization & Demobilization	$22.7/mi	$23.2/mi
TOTAL COST	$476/mi	$487/mi

Overhead, Indirect and Profit Costs

The overhead and indirect costs for herbicide application are determined by using ten percent of the total costs, including mobilization and demobilization, as discussed above in the General Assumptions section. Table 25 demonstrates a sample calculation of the overhead and indirect costs associated with the total cost of $271 per mile and a mobilization and demobilization cost of $13.60 per mile.

Table 25: Sample Calculation of Overhead and Indirect Cost. Average U.S. city data, 1991 dollar base

Given:	Total Cost = $271/Mile
	Mobilization and Demobilization = $13.6/Mile
	Overhead and Indirect = 10%
Find:	Overhead and Indirect Costs per Mile
Calculation:	
($271/mile) + ($13.60/mile) = $285/mile	
($285/mile) * (10%) = $28.50/mile	

The profit cost can be calculated in a similar manner by taking 15 percent, as discussed previously, of the total costs plus mobilization and demobilization costs. A sample calculation for computing overhead and indirect costs per mile is included as Table 26. Table 27 summarizes the overhead and indirect cost and the profit for each item on a per mile basis. The total U.S. average city cost (1991 dollar base) for herbicide application ranges from $356 to $609 per mile. The final herbicide application costs were converted to Anchorage, Alaska data base, using the Construction Cost Index as demonstrated in Chapter 4, and are included in Table 27.

Table 26: Sample Calculation for Herbicide Application Profit. Average U.S. city data, 1991 dollar base

Given:	Total Cost = $271 per Mile
	Mobilization and Demobilization = 15%
Find:	Profit per Mile
Calculation:	
($285/mile) * (15%) = $42.80/mile	

Table 27: Summary of Overhead, Indirect, Profit and Total Costs for Herbicide Applications. 1991 dollar base

Total Costs	Overhead & Indirect	Profit	Total Avg. U.S. City Costs	Total Anchorage AK Costs
		Productivity of 67 miles/day		
$285/mi	$28.50/mi	$42.80/mi	$365/mi	$479/mi
$476/mi	$47.60/mi	$71.40/mi	$595/mi	$781/mi
		Productivity of 33 miles/day		
$297/mi	$29.70/mi	$44.60/mi	$371/mi	$487/mi
$487/mi	$48.70/mi	$73.10/mi	$609/mi	$799/mi

Brush Cutting

This operation consists of using a brush cutter to remove vegetation, mainly woody species, along the track, on the shoulders and in the ballast area. Most brush cutters have the capability of reaching into the wider right-of-way to cut vegetation, but this analysis concentrates on vegetation control in the immediate ballast area. An assumption is made based on studies by Sheahan (1988) that this equipment is in operation for 100 shifts per year, exclusively in the summer months.

Equipment Costs

The initial purchase price, maintenance costs, and fuel costs are included in the equipment costs. The 1986 purchase price for a brush cutter is $180,000 (Sheahan, 1988). A life span of ten years with no salvage value after that time is assumed. This cost translated to the 1991 dollar base, using CPI-US as previously demonstrated, is $213,000 and when amortized into a yearly cost is $34,700. A maintenance cost of 20 percent of the purchase price (Cataldi and Elkaim, 1980), $42,700, is assumed for this operation as discussed earlier. Sheahan (1984) lists yearly maintenance costs for a brush cutter as $34,000. Translated into 1991 dollar base this is $42,300, which corresponds closely with Cataldi and Elkaim's maintenance costs. The yearly fuel cost is $6,000 (Sheahan, 1988), and when translated into the 1991 dollar base is $7,460. Table 28 summarizes the equipment costs.

Table 28: Summary of Annual Brush Cutter Equipment Costs. Average U.S. city data, 1991 dollar base

Amortized Purchase Price	$34,700
Maintenance Costs	$42,700
Fuel Costs	$7,460
TOTAL ANNUAL EQUIPMENT COSTS	$84,900

Labor Costs

The typical crew size for a brush cutting operation is two workers (Sheahan, 1988). The daily labor rate as shown in Table 10 is $255 for a grade 4 operator and $153 for a laborer. If the brush cutter operates 100 shifts a year at one shift per day as discussed earlier, the yearly labor cost is $40,700. A sample calculation of this procedure is shown in Table 16.

Mobilization and Demobilization Costs

Five percent of equipment and labor costs was assumed for mobilization and demobilization as previously discussed. Labor and equipment costs, the sum of $84,900 and $40,700, total $126,000 yearly, which result in a $6,280 expenditure for mobilization and demobilization; when added to the equipment and labor expenses of $126,000, the sum is $132,000 annually.

Overhead, Indirect, and Profit Costs

The annual overhead and indirect costs for this type of operation are assumed, as discussed earlier, to be ten percent of the total equipment, labor, mobilization, and demobilization costs which is $132,000. This is $13,200 yearly for overhead and indirect costs. A sample overhead and indirect cost calculation is shown in Table 25.

Profit for this operation is assumed to be 15 percent, as discussed in the General Assumptions Section, of the total expenses listed which are $132,000 (sum of equipment, labor, mobilization and demobilization costs). This results in a profit of $19,800 yearly. The yearly costs per item are summarized in Table 29 for brush cutting operations.

Table 29: Summary of Annual Brush Cutting Costs. Average U.S. city data, 1991 dollar base

Amortized Purchase Price	$34,700
Maintenance Costs	$42,700
Fuel Costs	$7,460
Labor Costs	$40,700
Mobilization and Demobilization	$6,280
Overhead and Indirect Costs	$13,200
Profit	$19,800
TOTAL YEARLY COST	$165,000

Brush Cutting Costs per Mile

Methods of vegetation control can be more easily compared when the data are in a cost per mile form. Equipment productivity must be considered to change the yearly costs into a cost per mile value. Sheahan (1988) reports a daily brush cutting productivity of 0.89 miles of right-of-way, with a 24 foot wide swath cut. Another source (Anonymous, 1970) states that 1.12 miles of right-of-way was cut in a day with a 28 foot width. Considering one day as a shift and the given productivities, results in costs per mile (average U.S. city data, 1991 dollar base) of $1850 and $1,470, respectively. A sample calculation of the per mile conversion is included as Table 30. The brush cutting cost per mile (1991) when converted to Anchorage, Alaska data base, as shown earlier in Chapter 4, is $2,430 for 0.89 miles per day productivity and $1,930 for 1.12 miles per day productivity.

Table 30: Sample Calculation for per Mile Conversion for Brush Cutting. Average U.S. city data, 1991 dollar base

Given: Yearly Cost = $165,000
Productivity = 0.89 Miles per Day
Operate 100 Shifts per Year

Find: Cost per Mile for Brush Cutting

Calculation:

($164,869/year) * (1 year/100 shifts) * (1 shift/0.89 miles) = $1,850/mile

Each cost item for brush cutting has been converted to a cost per mile for the specific cost components and is reported in Table 31.

Table 31: Summary of Brush Cutting Costs per Mile. Average U.S. city data, 1991 dollar base

Productivity Rates	0.89 mi/day	1.12 mi/day
Purchase Price	$390/mi	$310/mi
Maintenance Costs	$480/mi	$381/mi
Fuel Costs	$84/mi	$67/mi
Labor Costs	$458/mi	$364/mi
Mobilization & Demob.	$71/mi	$56/mi
Overhead and Indirect	$148/mi	$118/mi
Profit	$222/mi	$177/mi
TOTAL COST FOR BRUSH CUTTING	$1,850/mi	$1,470/mi

Ballast Regulator

In this operation the ballast regulator is used to scrape away vegetation along the shoulders of the ballast and to brush vegetation between the rails. An average equipment usage with a yearly use of 200 shifts is assumed per Cataldi and Elkaim (1980) as discussed earlier.

Equipment Costs

The purchase cost, maintenance costs, and fuel costs must be considered in determining the cost of the equipment. The original purchase cost (1986) of a ballast regulator is about $90,000 (Burns, 1987a). This translates, using CPI-US as demonstrated previously, into a 1991 cost of $107,000. If the machine has a 14 year life, is rebuilt for $32,000 (1991 dollar base) after an eight year period (Burns, 1987a), and has a zero salvage value, the yearly cost is $16,500. An interest rate of ten percent is assumed as discussed previously. Table 32 shows this calculation.

Table 32: Sample Calculation of Amortized Ballast Regulator Cost. Average U.S. city data, 1991 dollar base

Given: Ballast Regulator Purchase Price = $107,000
Ballast Rebuild Cost = $32,000
Equipment Life = 14 years
Must Rebuild Equipment After 8 Years
Interest Rate = 10%

Find: Yearly Cost for Ballast Regulator

Calculation:

Equipment Price =
Purchase Price + (P/F, 10%, 8) * Rebuild Price

P/F, 10% for 8 years = 0.4665
Equipment Price = $107,000 + $32,000 * (0.4665)
Equipment Price = $121,900

Yearly Cost = (A/P, 10%, 14) * Equipment Price

A/P, 10% for 14 years = 0.13575
Yearly Cost = $121,900 * (0.13575)
Yearly Cost = $16,500

A yearly maintenance cost of 20 percent of the purchase price, following Cataldi and Elkaim's (1980) guidelines is assumed. This results in an annual maintenance cost of $21,300. The fuel cost to operate this equipment is $33 per shift (Burns, 1987a) which translates, using the CPI-US conversion as described earlier, to a cost of $39 per shift in a 1991 dollar base. When 200 shifts per year with one shift per day are considered, the annual fuel cost is $7,800. The total equipment costs are $45,700 annually, and Table 33 includes a summary of these costs.

Table 33: Summary of Annual Ballast Regulator Equipment Costs. Average U.S. city data, 1991 dollar base

Amortized Purchase Price	$16,500
Maintenance Costs	$21,300
Fuel Costs	$7,800
TOTAL YEARLY EQUIPMENT COSTS	$45,700

Labor Cost

It is assumed that a ballast regulator requires a two person crew for operation, one laborer and one equipment operator. The operator (grade 4) was a daily labor cost of $255, and the laborer a cost of $153 as shown in Table 10. Assuming a moderate equipment usage of 200 shifts per year, according to Cataldi and Elkaim's guidelines as discussed earlier, the total yearly labor cost is $81,500. A sample annual labor cost calculation is demonstrated in Table 16.

Mobilization and Demobilization Costs

An assumption of five percent of the total labor and equipment, as mentioned previously, is used to determine the cost to mobilize and demobilize a ballast regulator. The cost for labor and equipment is the sum of $81,500 and $45,700 respectively which totals $127,000. The resulting mobilization and demobilization cost is $6,360. Table 23 demonstrates a sample calculation for mobilization and demobilization costs. The total cost thus far is the sum of equipment, labor, mobilization, and demobilization which is $127,000 plus $6,360 for $133,400 annually.

Overhead, Indirect, and Profit Costs

The overhead and indirect costs are calculated using the assumption, discussed previously, of ten percent of the total annual costs calculated, which equals $133,400 yearly. The yearly overhead and indirect cost is $13,300.

Profit for this operation is calculated as discussed in the previous sections, using the assumption of 15 percent of the total equipment, mobilization and demobilization costs. The yearly costs are $133,400 as calculated previously, and this results in $20,000 annually for profit.

The total annual costs (average U.S. city data, 1991 dollar base) for vegetation control with a ballast regulator are $167,000, and the yearly per item costs for both average

U.S. city data and Anchorage, Alaska data are summarized in Table 34.

Table 34: Summary of Annual Ballast Regulator Costs. 1991 dollar base

	Average U.S. City Costs	Anchorage AK Costs
Amortized Purchase Price	$16,500	$21,600
Maintenance Costs	$21,300	$27,900
Fuel Costs	$7,800	$10,200
Labor Costs	$81,500	$107,000
Mobilization & Demobilization	$6,360	$8,340
Overhead and Indirect Costs	$13,300	$17,400
Profit	$20,000	$26,200
TOTAL ANNUAL COST	$167,000	$219,000

Ballast Regulator Costs per Mile

The equipment productivity is used to determine the per mile cost of vegetation control by a ballast regulator. For this calculation the productivity is assumed to be 1,000 feet per hour, suggested by the Alaska Railroad (Preston, 1990), with the equipment operating five hours per shift (the workers are working eight hours). As with the alternatives discussed previously, herbicide application and brush cutting, the equipment worked eight hours daily. The increased maintenance and operational difficulties, and the amount of time it takes to clear the track for other traffic, restricts the equipment productivity to five hours per shift. The ballast regulator is used for one shift daily. Following Cataldi and Elkaim's (1980) equipment usage guidelines of 200 shifts yearly, the cost per mile (average U.S. city data, 1991 dollar base) is $880 for ballast regulator vegetation control. Table 35 summarizes ballast regulator vegetation control costs per mile.

Table 35: Summary of Ballast Regulator Costs per Mile. 1991 Dollar Base

	Average U.S. City Costs	Anchorage AK Costs
Amortized Purchase Price	$87/mi	$114/mi
Maintenance Costs	$112/mi	$150/mi
Fuel Costs	$41/mi	$54/mi
Labor Costs	$430/mi	$564/mi
Mobilization and Demobilization	$34/mi	$45/mi
Overhead and Indirect Costs	$70/mi	$92/mi
Profit	$106/mi	$139/mi
TOTAL PER MILE COST	$880/mi	$1,160/mi

Reballasting

A reballasting operation requires a ballast regulator and the associated personnel as listed in Table 35 along with raw materials and additional equipment. To control vegetation with this technique, ballast is added to the track structure to deter plant activity by providing shade and essentially smothering the plant growth. For this analysis, it is assumed that a three inch cover of ballast material, the typical amount of ballast distributed during reballasting operations on the Alaska Railroad (Durst, 1990), is sufficient to control plant growth in the ballast area and along the shoulders. This amount of ballast is assumed to control vegetation for one treatment life, which is subsequently discussed in Chapter 6.

A ballast regulator, in general, has a reach of ten feet on each side of the track centerline. This reach limits the area of ballast application. In standard track maintenance operations, as described by the Alaska Railroad, a total width of ten feet of ballast is applied to the roadbed, generally five feet left and right of centerline. In this analysis, a width of ten feet will be used so that reballasting for track maintenance purposes and vegetation control are comparable.

Equipment Costs

Equipment costs for reballasting include all the costs associated with ballast regulator operations as previously specified in the Ballast Regulator Section. The cost of additional laborers, support, and transport for the ballast material that is needed for reballasting, is included in the cost of the materials. Table 33 is a summary of the annual equipment costs for a ballast regulator which are $45,700 (average U.S. city data, 1991 dollar base).

Labor Costs

The labor requirements for reballasting are similar to those used for ballast regulator operations. It is assumed that additional labor is not required for reballasting. The labor cost, as calculated in the previous Ballast Regulator

Section, for a two person crew of a laborer and a grade 4 equipment operator, is $81,500 annually (average U.S. city data, 1991 dollar base).

Material Costs

Burns (1987a) has developed cost estimates on the price of railroad ballast. His assumptions were that the ballast was obtained in a rural environment and that the on-line movement of the ballast to the application site was less than 250 miles. The price for ballast varies with the type of material that is used and is a function of the quality of the material and its weight. Ballast prices range from $3.10 (1991) per ton for ferrous metal slag (when 300,000 or more tons are purchased) to $7.70 (1991) per ton for harder granites (Burns, 1987a).

Ferrous metal slag weighs approximately one ton per cubic yard and granite weighs about 1.45 tons per cubic yard (Burns, 1987a). A three inch lift of material over the old ballast ten feet wide, results in 489 cubic yards of material per mile of track. This gives a materials cost of $1,520 per mile of track reballasted with ferrous metal slag, and $5,450 per mile of track reballasting with granite ballast. Table 36 demonstrates a calculation of the materials cost per mile.

Table 36: Sample Calculation of Material Cost per Mile. Average U.S. city data, 1991 dollar base

<u>Given</u>: Ballast Spread on a 10 foot Width
Metal Slag Weighs 1 Ton per Cubic Yard
Granite Weighs 1.45 Tons per Cubic Yards
Materials Cost: Metal Slag = $3.10 per Ton
Granite = $7.70 per Ton

<u>Find</u>: Cost per Mile for Ballast

<u>Calculation</u>:
Volume of Material: (10 ft) * (1 feet/12 inches) * (1 cubic yard/27 cubic feet) * (5280 feet/mile)
Volume of Material = 489 cubic yards

Material Cost:
Metal Slag -
(1 ton/cubic yard) * (489 cubic yards/mile) * ($3.10/ton) = $1,520/mile

Granite -
(1.45 ton/cubic yard) * (489 cubic yards/mile) * ($7.70/ton) = $5,450/mile

In addition to the actual cost of the ballast, the cost to transport the material must be considered. The material transport cost varies with the material type, the transport distance to the application site, and whether the material is hauled on the rail or by road. Burns (1987a) lists a transport cost for ballast based on a United States average for single car movement, assuming there is no switching, along a company owned railroad line. He lists on-line costs (translated to 1991 dollar base using CPI-US) for slag that range from $0.01 to $0.021 per cubic yard of material and mile of transport, and costs (translated to 1991 dollar base using CPI-US) for granite from $0.017 to $0.05 per cubic yard of material and mile of transport. According to Burns

(1987a), transport distances of ballast can vary from a low of ten miles to a high of 1,000 miles. He suggests that a 250 mile transport distance is the average for major railroads in the United States. It is assumed that the cost for ballast cars to carry the material and a support crew for its placement is included in the transport cost of the ballast.

When a haul distance of 250 miles is considered, with a placement volume of 489 cubic yards per mile, the ballast transportation costs per mile can be determined. This transportation cost is added to the materials cost to determine the total cost per mile of the ballast. A sample calculation is demonstrated in Table 37 for metal slag with a materials cost of $1,520 per mile. Table 38 summarizes the ballast costs per mile.

Table 37: Sample Calculation for Ballast Material Costs per Mile. Average U.S. city data, 1991 dollar base

<u>Given</u>: Transportation Cost = $0.01/cubic yard-mile
Quantity = 489 per Mile
Distance = 250 Miles
<u>Find</u>: Total Ballast Cost for Metal Slag

<u>Calculation</u>:

Transportation Costs
($0.01/cubic yard-mile) *(489 cubic yard/mile) * (250 miles) = $1,220/mi

Materials Costs = $1,520/mi

Total Ballast Cost = Transport Costs + Materials Costs
$1,520/mile + 1,220/mile = $2,740/mile

Table 38: Summary of Ballast Costs per Mile. Average U.S. city data, 1991 dollar base

Transport Rate	Transport Cost	Material Cost	Total Cost
	METAL SLAG		
\$0.01/cubic yard-mile	\$1,220/mi	\$1,515/mi	\$2,740/mi
\$0.021/cubic yard-mile	\$2,530/mi	\$1,515/mi	\$4,050/mi
	GRANITE		
\$0.017/cubic yard-mile	\$2,080/mi	\$5,450/mi	\$7,530/mi
\$0.05/cubic yard-mile	\$3,680/mi	\$5,450/mi	\$9,130/mi

The ballast cost per mile can be converted to a yearly cost using a productivity of 1,000 feet per hour for this operation, which is similar to ballast regulator operations discussed previously. Table 39 demonstrates a sample calculation for metal slag with a total per mile cost of \$2,740. The equipment usage following Cataldi and Elkaim's guidelines is 200 shifts per year, with one shift per day and an equipment workday of five hours. The equipment work day is five hours long, similar to the ballast regulator as discussed previously, because of increased operational and maintenance difficulties associated with this equipment. Table 40 is a summary of the yearly ballast costs.

Mobilization and Demobilization Costs

The mobilization and demobilization costs for reballasting are calculated using an assumption of five percent of the equipment, labor, and materials costs as discussed previously. Table 40 shows that the material cost

Table 39: Sample Calculation of Conversion to Annual Ballast Cost. Average U.S. city data, 1991 dollar base

Given: Cost per Mile = $2,740
Productivity = 1,000 Feet per Hour
5 Hours per Shift, 1 Shift per day
Operate for 200 Shifts per Year

Find: Yearly Ballast Cost for Metal Slag

Calculation:
Ballast Cost/year = ($2,740/mile) * (1 mile/5,280 feet) * (1,000 feet/hour) * (5 hours/shift) * (200 shifts/year)

Ballast Cost = $519,000/year

Table 40: Summary of Annual Ballast Material Cost. Average U.S. city data, 1991 dollar base

Transport Rate	Per Mile Cost	Yearly Cost
	METAL SLAG	
$0.01/cubic yard-mile	$2,740/mi	$519,000
$0.021 cubic yard-mile	$4,050/mi	$767,000
	GRANITE	
$0.017 cubic yard-mile	$7,530/mi	$1.45 Million
$0.05 cubic yard-mile	$9,130/mi	$1.73 Million

varies, depending on the transportation rate and the material type, from $2,740 to $9,130 per mile which is $519,000 to $1.73 million annually (average U.S. city values, 1991 dollar base).

If the mobilization and demobilization costs were calculated as a percentage of these wide ranging material costs, annual mobilization and demobilization costs would vary from $32,300 to $92,800. This would imply that the price of the material influences the ease or difficulty of getting equipment and workers to the job site. This is not true as the equipment used is the same regardless of the type of ballast spread on the track. To resolve this problem, an average value of the materials cost, $5,860 per mile which is $1.12 million per year, will be added to the equipment and labor costs and used to calculate the mobilization and demobilization cost. This approach is different from the one used in the previous vegetation control alternatives.

The total equipment and labor costs are the sum of $45,700 and $81,500 which equals a yearly cost of $127,000. When added to the average yearly ballast cost of $1.12 million this results in a subtotal of $1.24 million. Mobilization and demobilization is five percent of that cost, or $62,200 per year, which is $382 per mile based on the average ballast costs (average U.S. city data, 1991 dollar base).

Overhead, Indirect and Profit Costs

The overhead and indirect costs were calculated using ten percent of the total equipment, labor, and materials cost, as discussed in the previous section. Table 41 includes the overhead and indirect costs for each type of material and the total reballasting cost, including the overhead and indirect expenses.

Table 41: Summary of Annual Overhead and Indirect Costs for Reballasting. Average U.S. city data, 1991 dollar base

Ballast Cost	Equipment & Labor	Mob. & Demob.	Subtotal Costs	Overhead & Indirect	Total
		METAL SLAG			
$519,000	$127,000	$62,200	$708,000	$70,800	$779,000
$767,000	$127,000	$62,200	$956,000	$95,600	$1.05 mil*
		GRANITE			
$1.45 mil	$127,000	$62,200	$1.64 mil	$164,000	$1.80 mil
$1.73 mil	$127,000	$62,200	$1.92 mil	$192,000	$2.11 mil

* mil = million

The profit for reballasting will be computed as 15 percent of the project cost as discussed earlier. Table 42 summarizes the profit and total yearly reballasting cost.

Table 42: Summary of Annual Profit Costs for Reballasting. Average U.S. city data, 1991 dollar base

Cost Subtotal	Profit	New Total
	METAL SLAG	
$779,000	$117,000	$896,000
$1.05 million	$158,000	$1.21 million
	GRANITE	
$1.80 million	$270,000	$2.07 million
$2.11 million	$317,000	$2.23 million

Table 43 is a summary of the yearly cost for reballasting for each cost item from Tables 35, 40, 41, and 42.

Table 43: Annual Cost Summary for Reballasting. Average U.S. city data, 1991 dollar base

Amortized Purchase Price		$16,500
Maintenance Costs		$21,300
Fuel Costs		$7,800
Labor		$81,500
Mobilization and Demobilization		$62,200
	METAL SLAG Transportation Rate (dollars per cubic yard-mi)	
	$0.01	$0.021
Materials Cost	$519,000	$767,000
Overhead and Indirect	$70,800	$95,600
Profit	$117,00	$158,000
TOTAL	$896,000	$1.21 million
	GRANITE Transportation Rate (dollars per cubic yard-mi)	
	$0.017	$0.05
Materials Cost	$1.45 million	$1.73 million
Overhead and Indirect	$164,000	$192,000
Profit	$270,000	$317,000
TOTAL	$2.07 million	$2.43 million

To convert the annual cost data to a per mile basis, the equipment productivity is taken into consideration. As stated previously, the productivity of the reballasting operation is 1,000 feet per hour based on a five hour equipment workday and an equipment usage of 200 shifts per year. The cost per mile (average U.S. city data, 1991 dollar base) for reballasting with metal slag ballast ranges from $4,730 to $6,390, and for granite from $10,930 to $12,800. The cost of the reballasting operation is reported for a range of values because it is influenced by the transportation rate used in the calculation. The per mile reballasting costs for Anchorage, Alaska data base (1991 dollar base) using the Construction Cost Index conversion as shown in Chapter 4, range from $6,210 to $8,380 for metal slag and $14,300 to $16,800 for granite ballast. Table 44 is a summary of the per mile cost for individual cost components of reballasting for the average U.S. city data base.

Table 44: Per Mile Cost Summary for Reballasting. Average U.S. city data, 1991 dollar base

Amortized Purchase Price		$87.1/mi
Maintenance Costs		$112/mi
Fuel Costs		$41.2/mi
Labor		$430/mi
Mobilization and Demobilization		$328/mi
METAL SLAG		
Materials Cost	$2,740/mi	$4,050/mi
Overhead and Indirect	$374/mi	$505/mi
Profit	$618/mi	$834/mi
TOTAL	$4,730/mi	$6,390/mi
GRANITE		
Materials Cost	$7,660/mi	$9,130/mi
Overhead and Indirect	$866/mi	$1,010/mi
Profit	$1,430/mi	$1,670/mi
TOTAL	$10,930/mi	$12,800/mi

Undercutting

The undercutting operation is complex as it requires several pieces of equipment and good coordination of labor forces to accomplish. Undercutting, as described previously in Chapter 2: Literature Review, generally consists of removing a specified amount of fouled ballast from within and under the ties, screening the material (in an undercutting/cleaning operation), and adding sufficient new material to fill the voids left by the wasted ballast. For these calculations an undercutting/cleaning operation is selected such that a minimum amount of new ballast will have to be applied. The minimum cut an undercutter can make below the ties is six inches. This six inch cut and a 200 shift per year machine usage, as suggested by Cataldi and Elkaim's guidelines (1980) discussed above, will be assumed for the cost calculations. According to product literature by Kershaw Manufacturing Company (Kershaw, unknown) the minimum support for an undercutting operation is one undercutter, one production tamper, and a ballast regulator. A minimum crew consists of three foremen, two assistant foremen, three machine operators, and ten laborers. These equipment and labor guidelines are used for the following cost analyses.

It was assumed that the track is in sufficient condition so that replacement of a large number of ties and spikes is not required. If the track is in poor condition, these replacements may greatly increase the cost of undercutting.

Equipment Costs

The undercutting operation requires a ballast regulator, a tamper, and an undercutter. The equipment costs associated with the ballast regulator are outlined in Table 32 in the Ballast Regulator Section.

The 1980 purchase price of a production tamper is $140,000 and yearly maintenance comprises 30 percent of the initial cost of the equipment (Cataldi and Elkaim, 1980). Translated into 1991 dollar base, using the CPI-US conversion, the purchase price is approximately $213,000. The average expected life of a tamper is seven years (Burns, 1987a) so when the purchase price is amortized over that time using a ten percent interest rate, the yearly cost is $43,800. Table 9 shows a sample calculation of the conversion to an annual cost. The annual maintenance cost is 30 percent of the $213,000 purchase price or about $63,900 per year. The fuel cost is $37 (1980) for an eight hour shift (Cataldi and Elkaim, 1980), and when translated to the 1991 dollar base is $56 per shift. When the standard use of 200 shifts per year (Burns, 1987a) is considered, the annual fuel cost is $11,200. The total equipment cost for the tamper is $119,000 yearly. Table 45 summarizes annual equipment costs for the tamper.

Table 45: Summary of Annual Tamper Equipment Costs. Average U.S. city data, 1991 dollar base

Amortized Purchase Price	$43,800
Maintenance Costs	$63,900
Fuel Costs	$11,200
TOTAL YEARLY TAMPER COST	$119,000

The undercutter purchase price ranges from \$500,000 (Anonymous, 1975a) to \$850,000 (Cataldi and Elkaim, 1980). When converted to the 1991 dollar base, using CPI-US as demonstrated earlier, the purchase costs are \$1.18 million and \$1.29 million, respectively. When these costs are amortized, using a ten percent interest rate, over an assumed eight year equipment life, the resulting yearly costs are \$221,000 and \$242,000. Cataldi and Elkaim (1980) list undercutter maintenance costs as \$3,025 per mile (1980 dollar base), which translates to \$4,590 per mile in a 1991 dollar base. When a yearly use of 104 miles is considered as recommended by Cataldi and Elkaim (1980), the annual maintenance cost is \$478,000. The fuel cost of \$104 per shift (Cataldi and Elkaim, 1980) converted to a 1991 dollar base is \$158 per shift. When a 200 shift per year equipment usage is assumed, the yearly fuel cost is \$31,600. A summary of equipment cost for an undercutter is listed as Table 46.

Table 46: Summary of Undercutter Equipment Costs. Average U.S. city data, 1991 dollar base

Amortized Purchase Price	\$221,000	to	\$242,000
Maintenance Costs			\$478,000
Fuel Costs			\$31,600
TOTAL ANNUAL EQUIPMENT COSTS	\$731,000	to	\$752,000

The annual equipment cost for the undercutting operation when the cost of a ballast regulator, a tamper, and an undercutter are added together ranges from $896,000 to $917,000 depending on the equipment purchase price. Table 47 is a summary of the total equipment costs.

Table 47: Summary of Annual Undercutting Operation Equipment Costs. Average U.S. city data, 1991 dollar base

Ballast Regulator			$45,700
Tamper			$119,000
Undercutter	$731,000	to	$752,000
TOTAL ANNUAL EQUIPMENT COST	$896,000	to	$917,000

Labor Costs

As noted previously, the labor requirements for this operation are three foremen, two assistant (track) foremen, three machine operators, and ten laborers. Daily wage rates from Table 10 will be used in conjunction with a 200 shift per year equipment usage. Table 48 summarizes the labor costs.

Table 48: Summary of Annual Labor Costs for the Undercutting Operation. Average U.S. city data, 1991 dollar base

Position	Wage	Number Workers	Daily Total	Yearly Total
Foremen	$287	3	$861	$172,000
Track Foremen	$176	2	$352	$70,300
Machine Operators	$255	3	$764	$153,000
Laborers	$153	10	$1,530	$305,000
TOTAL			$3,500	$700,000

Materials Costs

For the undercutting/cleaning operation the amount of ballast recovered influences the cost of the replacement materials. For this analysis, three different recovery rates were considered: no recovery, 25 percent recovery, and 50 percent recovery. According to Alaska railroad personnel (Preston, 1990), the rate that parallels actual track conditions most closely is probably 25 percent recovery or less. In areas where track ballast conditions are very good, higher recovery rates may be found. The quantity of ballast that is required with no material recovery is calculated assuming that there is eight inches of ballast to the bottom of the ties, and a minimum cut of six inches is made below the tie for a width of ten feet. Using these values, the total number of cubic yards of ballast required is 2,280 per mile. A sample calculation is demonstrated in Table 49.

Table 49: Sample Calculation of Ballast Quantity Required for Undercutting

Given:	Depth of Ballast to Bottom of Tie = 8 Inches Depth of Undercutting = 6 Inches Width of Undercutting = 10 Feet
Find:	Quantity of Ballast Required for Undercutting

Calculation:
8 inches + 6 inches = 14 inches of ballast
Ballast Quantity = (14 inches) *(12 inches/foot) * (10 feet) * (5,280 feet/mile) *(1 cubic yard/27 cubic feet)

Ballast Quantity = 2,280 cubic yards/mile

Two different ballast materials are considered for this operation, metal slag and granite. The price per ton for the ballast and the number of tons per cubic yard are reported in the section on Reballasting. Considering this information, the price per mile for each kind of ballast can be computed in a similar manner to the calculation in Table 36. For metal slag the cost per mile is $7,070 and for granite the cost per mile is $25,500.

Transportation costs must be considered with the raw material price of the ballast. As mentioned in the Reballasting Section, the transportation cost of metal slag ballast ranges from $0.01 to $0.021 per cubic yard, and from $0.017 to $0.05 per cubic yard of granite. An assumed transport distance of 250 miles is used. A summary of the ballast costs is produced in Table 50. The two values of each cost item in Table 50 represent the range of costs associated with different material transport rates.

Table 50: Summary of Ballast Costs per Mile with No Recovery. Average U.S. city data, 1991 dollar base

	METAL SLAG	
Material Cost	Transport Cost	Total Cost
$7,070/mi	$5,700/mi	$12,800/mi
$7,070/mi	$11,970/mi	$19,000/mi
	GRANITE	
Material Cost	Transport Cost	Total Cost
$25,500/mi	$9,690/mi	$35,200/mi
$25,500/mi	$28,500/mi	$54,000/mi

The materials cost for undercutting can also be calculated for 25 percent and 50 percent recovery of the ballast. For 25 percent recovery, 75 percent of the ballast calculated for no recovery would be needed. Similarly, for 50 percent recovery, 50 percent of the material is needed. The price per mile for the different recoveries is shown in Table 51 with a range of costs for each item based on different material transport rates.

Table 51: Summary of Ballast Costs per Mile for Various Recovery Rates. Average U.S. city data, 1991 dollar base

	METAL SLAG	
No Recovery	25% Recovery	50% Recovery
$12,800/mi	$9,600/mi	$6,400/mi
$19,000/mi	$14,300/mi	$9,500/mi
	GRANITE	
No Recovery	25% Recovery	50% Recovery
$35,200/mi	$26,400/mi	$17,600/mi
$54,000/mi	$40,500/mi	$27,000/mi

These per mile costs can also be converted into annual costs using the productivity rate of the undercutting operation. Kershaw Manufacturing Company (Kershaw, unknown) states that this operation has a productivity of 2,000 feet per day for an eight hour day when a six inch cut is made. For this illustration, a five hour machine operating time will be used as a conservative estimate and to compensate for down time from mechanical problems or time to clear the track for other vehicles. A sample calculation is shown in Table 52 for conversion to an annual cost of metal slag.

Table 53 lists annual values for the per mile material costs with varying recovery rates. Two values are shown for each recovery rate because of the variance in material transport costs.

Table 52: Sample Calculation of per Mile to Annual Cost Conversion. Average U.S. city data, 1991 dollar base

Given: No Ballast Recovery
Ballast (Metal Slag) Cost per Mile = $12,800
Productivity = 2,000 Feet per Shift
Work for 5 Hours per Shift, 1 Shift per Day
Equipment Operates for 200 Shifts per Year

Find: Yearly Ballast Cost for Metal Slag

Calculation:

Ballast Cost = ($12,800/mile) * (1 miles/5,280 feet) * (2,000 feet/8 hour) * (5 hour/shift) * (200 shifts/year)

Ballast Cost = $606,000/year

Table 53: Summary of Annual Ballast Costs for Various Recovery Rates. Average U.S. city data, 1991 dollar base

	METAL SLAG	
No Recovery	25% Recovery	50% Recovery
$606,000	$455,000	$303,000
$900,000	$677,000	$450,000
	GRANITE	
No Recovery	25% Recovery	50% Recovery
$1.67 million	$1.25 million	$833,000
$2.26 million	$1.92 million	$1.28 million

Mobilization and Demobilization Costs

The mobilization and demobilization costs were determined by a five percent assumption of the equipment and labor costs as discussed previously in the General

Assumptions Section. The total annual equipment costs range from $896,000 to $917,000 and the labor is $700,000 yearly. This totals annual costs that range from $1.60 million to $1.62 million, respectively. Calculating the mobilization and demobilization costs for the undercutting operation poses similar problems as the reballasting operation because the total project price is dependent on the materials cost. For this case, an approach is used similar to that which was used for the reballasting cost estimate. The mobilization and demobilization costs are determined by averaging the ballast costs and adding them to the equipment and labor costs. The average value for the ballast, including the transportation costs, (average U.S. city data, 1991 dollar base) is $22,700 per mile which is $981,000 annually. Adding the ballast cost to the equipment and labor costs gives a range of $2.58 million and $2.60 million annually. Using the assumed five percent of these costs results in a range of $129,000 to $130,000 annually for mobilization and demobilization.

Overhead, Indirect and Profit Costs

The overhead and indirect costs are calculated by taking ten percent of the total cost of the vegetation control operation as discussed previously in the General Assumptions Section. Profit is calculated by taking 15 percent of the total project cost as discused earlier. The total costs are summarized in Table 54 along with the overhead, indirect and profit costs. For each recovery rate in Table 54 there are two values that reflect varying material transport costs.

Using the equipment productivity rate of 2,000 feet per shift, one shift per day, five hours per shift daily equipment utilization, and Cataldi and Elkaim's 200 shift per year assumption, the costs can be converted into a per mile value. Table 55 is a summary of the total per mile costs for the undercutting operation for the average U.S. city data base (1991 dollar base). Table 55 shows the same information in an Anchorage, Alaska data base. Both Tables 55 and 56 show two values for each recovery rate. This represents the variance due to different material transport rates.

Hand Clearing

This method of vegetation control employs a group of laborers that pull or cut vegetation, by hand, in the ballast area. It is a labor intensive chore requiring little or no equipment. Since the laborers are in the immediate track area, safety precautions should be taken in order to prevent accidents.

Table 54: Summary of Annual Undercutting Costs For Various Recovery Rates. Average U.S. city data, 1991 dollar base

	METAL SLAG	
	Subtotal Costs	
No Recovery	25% Recovery	50% Recovery
$3.32 million	$3.17 million	$3.01 million
$3.63 million	$3.41 million	$3.18 million
	Overhead and Indirect Costs	
No Recovery	25% Recovery	50% Recovery
$332,000	$317,000	$301,000
$363,000	$341,000	$318,000
	Profit	
No Recovery	25% Recovery	50% Recovery
$498,000	$476,000	$452,000
$545,000	$512,000	$477,000
	Total Annual Undercutting Costs for Metal Slag Ballast	
No Recovery	25% Recovery	50% Recovery
$4.15 million	$3.96 million	$3.76 million
$4.54 million	$4.26 million	$3.98 million
	GRANITE	
	Subtotal Costs	
No Recovery	25% Recovery	50% Recovery
$4.14 million	$3.96 million	$3.54 million
$4.99 million	$4.65 million	$4.01 million
	Overhead and Indirect Costs	
No Recovery	25% Recovery	50% Recovery
$414,000	$396,000	$354,000
$499,000	$465,000	$401,000
	Profit	
No Recovery	25% Recovery	50% Recovery
$621,000	$594,000	$531,000
$749,000	$698,000	$602,000
	Total Annual Undercutting Costs for Granite Ballast	
No Recovery	25% Recovery	50% Recovery
$5.18 million	$4.95 million	$4.43 million
$6.34 million	$5.81 million	$5.01 million

Table 55: Summary of per Mile Undercutting Costs for Various Recovery Rates. Average U.S. city data, 1991 dollar base

METAL SLAG Total Undercutting Cost per Mile		
No Recovery	25% Recovery	50% Recovery
$87,700/mi	$83,600/mi	$79,400/mi
$95,900/mi	$90,000/mi	$84,100/mi
GRANITE Total Undercutting Cost per Mile		
No Recovery	25% Recovery	50% Recovery
$109,000/mi	$105,000/mi	$93,600/mi
$134,000/mi	$123,000/mi	$106,000/mi

Table 56: Summary of per Mile Undercutting Costs for Various Recovery Rates. Anchorage, Alaska data, 1991 dollar base

METAL SLAG Total Undercutting Cost per Mile		
No Recovery	25% Recovery	50% Recovery
$115,000/mi	$110,000/mi	$104,000/mi
$126,000/mi	$118,000/mi	$110,000/mi
GRANITE Total Undercutting Cost per Mile		
No Recovery	25% Recovery	50% Recovery
$143,000/mi	$138,000/mi	$123,600/mi
$176,000/mi	$161,000/mi	$139,000/mi

Equipment Costs

For hand clearing, it is assumed that the only equipment required is for transportation of the workers to and from the desired site. This cost will be included in the mobilization and demobilization estimate, and thus is not included in this section. Small hand tools or gloves may be needed so an assumption is made that the costs of those items will be included in the overhead and indirect costs.

Labor Costs

As this process is labor intensive, a relatively large crew will be needed. For this estimate a crew of 20 laborers will be used. This crew size was chosen because when combined with the individual worker productivity, the crew can clear one mile of track in a day. One supervisor is needed for every ten workers so two supervisors will be used, for a total of 22 workers. The daily wage cost for laborers is $153 including benefits, as shown in Table 10, and if 20 laborers are used this totals $3,050. The supervisors (track foremen) cost $176 daily (Table 10), and for two of them the total is $352. Adding the laborers costs of $3,050 to the supervisors costs of $352, gives a total of $3,410 daily for labor.

For hand clearing (weeding and clipping vegetation with non-power tools), an assumption is made that one person can pull and clip 30 to 100 feet of vegetation along the track for a width of 24 feet, in one hour. This productivity is dependent greatly on the density and type of vegetation present, and the value was chosen based field estimates of small amounts of hand clearing done in 1989 along the Alaska Railroad (Johnson, 1990). For this productivity and assuming an eight hour work day, the cost per mile is $3,410. Table 57 shows a sample calculation assuming the worst case (most dense vegetation) of 30 feet per hour.

Table 57: Sample Calculation of Labor Rate per Mile for Hand Clearing. Average U.S. city data, 1991 dollar base

<u>Given</u>: Productivity = 30 Feet per Worker per Hour
22 Workers are on a Crew
Wage rate for Workers is $3,406 per Day
Personnel Work 8 Hours per Day

<u>Find</u>: Labor Rate per Mile of Track

<u>Calculation</u>:
Daily Wage = (20 laborers) * ($153/day) + (2 supervisors) * ($176/day) = $3,410/day

Crew Productivity = (30 feet/man-hour) * (22 workers) * (8 hours/day) * (5,280 feet/mile) = 1 mile/day

Labor Rate = ($3,410/day) * (1 day/1 mile)
Labor Rate = $3,410/mile

Mobilization and Demobilization Costs

For hand clearing, the mobilization and demobilization costs are five percent of the labor and equipment costs, as discussed in the General Assumptions section. Five percent of $3,410 per mile is $170 per mile for mobilization and demobilization.

Overhead, Indirect and Profit Costs

The overhead and indirect costs are calculated from the total of the equipment, labor, mobilization, and demobilization costs. Equipment and labor costs are $3,410 per mile, and mobilization and demobilization costs are $170 per mile. The sum of these items is $3,580, and ten percent, as discussed previously, of this cost is $358 per mile for overhead and indirect.

Profit is 15 percent of the sum of equipment, labor, mobilization, and demobilization as discussed in the General Assumptions section. The sum of these items is $3,580, as determined for the overhead and indirect cost calculation, and 15 percent of this value is $536 per mile. When all of these costs are added together the total cost for hand clearing, based on a 30 feet per worker per hour productivity for a 20 foot width, is $4,470 per mile. A summary of these costs and the total cost is shown as Table 58 for both the average U.S. city and the Anchorage, Alaska data base.

Table 58: Summary of Cost per Mile for Hand Clearing. 1991 dollar base

	Average U.S. City Cost	Anchorage AK Cost
Equipment	$0/mi	$0/mi
Labor	$3,410/mi	$4,470/mi
Mobilization and Demobilization	$170/mi	$223/mi
Overhead and Indirect	$358/mi	$470/mi
Profit	$536/mi	$703/mi
TOTAL COST FOR HAND CLEARING	$4,470/mi	$5,870/mi

SUMMARY

A summary of the vegetation control costs per mile for herbicide application, brush cutting, ballast regulator, reballasting, undercutting, and hand clearing are included in Table 59. The assumptions used in the analysis for each vegetation control method must be evaluated to reflect the conditions at a specific site. To compare the cost of the vegetation control methods to each other requires that the frequency for a particular method be considered. For example, if one method must be used yearly to control vegetation adequately and another method is effective for a five year period, then the costs for these methods cannot be directly compared without further manipulation.

Chapter 6 contains a comparison of the costs reported from the survey and the independent cost calculations determined in this chapter. A method to compare vegetation control techniques with different treatment lives is also discussed in Chapter 6 along with a discussion of the vegetation control benefits of maintenance procedures and how they can be assigned a portion of the vegetation control costs.

Table 59: Summary of Cost per Mile for Vegetation Control Methods Shown for Various Productivities. 1991 dollar base

Herbicides Productivity	Chemical Cost	Average U.S. City Cost	Anchorage AK Cost
67 miles/day	$260/mile	$365/mi	$479/mi
33 miles/day	$260/mile	$371/mi	$487/mi
67 miles/day	$442/mile	$595/mi	$781/mi
33 miles/day	$442/mile	$609/mi	$799/mi
Brush Cutting:	0.89 miles/day	$1,850/mi	$2,430/mi
	1.12 miles/day	$1,470/mi	$1,930/mi
Ballast Regulator		$881/mi	$1,160/mi
Reballasting	METAL SLAG:		
Transport Rate:	$0.01/cu yard-mi	$5,700/mi	$6,210/mi
	$0.021/cu yard-mi	$7,230/mi	$8,380/mi
	GRANITE:		
Transport Rate:	$0.017/cu yard-mi	$11,600/mi	$14,300/mi
	$0.05/cu yard-mi	$13,300/mi	$16,800/mi

Undercutting

METAL SLAG:

Average U.S. City Costs

No Recovery	25% Recovery	50% Recovery
$87,700/mi	$83,600/mi	$79,400/mi
$95,900/mi	$90,000/mi	$84,100/mi

Anchorage, Alaska Costs

No Recovery	25% Recovery	50% Recovery
$115,000/mi	$110,000/mi	$104,000/mi
$126,000/mi	$118,000/mi	$110,000/mi

GRANITE:

Average U.S. City Costs

No Recovery	25% Recovery	50% Recovery
$109,000	$105,000	$93,600
$134,000	$123,000	$106,000

Anchorage, Alaska Costs

No Recovery	25% Recovery	50% Recovery
$143,000/mi	$138,000/mi	$123,600/mi
$176,000/mi	$161,000/mi	$139,000/mi

		Average U.S. City Cost	Anchorage AK Cost
Hand Clearing		$4,470/mi	$5,870/mi

CHAPTER 6

COMPARISON OF VEGETATION CONTROL METHODS

INTRODUCTION

This chapter contains a comparison of the cost of vegetation control methods obtained in the survey procedure, as presented in Chapter 4, and the data determined by the independent cost analyses presented in Chapter 5. The survey data was modified to reflect a 1991 dollar base in the following sections. A discussion of the components that influence the cost of each method are included, and the methods of vegetation control are ranked in order of increasing cost per mile.

SURVEY DOLLAR BASE CONVERSION

The cost per mile of the various treatment methods as gathered from the survey data presented in Chapter 4 were converted to a 1991 dollar base using the CPI-US index as demonstrated in Chapter 5. Tables 60 through 62 summarize the cost per mile in 1991 dollar base for each vegetation control method.

The hand clearing cost (without the use of power tools), from Chapter 5, when converted to 1991 dollar base (average U.S. city data) was $4,470 per mile. The cost of burning vegetation, as reported by the survey, converted to a 1991 dollar base was $1,150 per mile.

Table 60: Summary of Herbicide Application Costs. 1991 dollar base

Railroad ID #	State City	Average U.S. City Cost	Anchorage AK Cost
11	AL Montgomery	$136/mi	$141/mi
14	Canada Vancouver	$423/mi $430/mi	$439/mi $447/mi
15	PA Pittsburgh	$90.4/mi $124/mi	$93.9/mi $129/mi
28	ID Boise	$64.6/mi $94.0/mi	$67.1/mi $97.7/mi
18	FL Jacksonville	$238/mi $298/mi	$247/mi $310/mi
41	Canada Winnipeg	$514/mi	$534/mi
49	IA Des Moines	$327/mi	$340/mi
56	MS Jackson	$363/mi $418/mi $423/mi	$377/mi $434/mi $438/mi
62	LA New Orleans	$311/mi	$323/mi
63	VA Norfolk	$124/mi	$129/mi
92	NE Omaha	$83.5/mi $86.3/mi	$86.7/mi $89.7/mi
94	VT Burlington	$101/mi	$105/mi
99	WA Tacoma	$151/mi $200/mi	$157/mi $208/mi
97	WI Milwaukee	$65.9/mi $186/mi	$68.5/mi $193/mi
93	Pa Pittsburgh	$90.4/mi $105/mi	$94.9/mi $109/mi
	AVERAGE VALUE =	$188/mile	$195/mile

Table 61: Summary of Brush Cutting Costs. 1991 dollar base

Railroad ID #	State City	Average U.S. City Cost	Anchorage AK Cost
14	Canada Vancouver	$239/mi	$248/mi
20	IL Chicago	$205/mi	$213/mi
18	FL Jacksonville	$1,190/mi	$1,240/mi
56	MS Jackson	$408/mi	$424/mi
92	NE Omaha	$2,020/mi	$2,100/mi
96	WI Madison	$22.3/mi	$23.2/mi
77	NY Rochester	$430/mi	$447/mi
	AVERAGE VALUE =	$720/mile	$749/mile

Table 62: Summary of Ballast Regulator Costs. 1991 dollar base

Railroad ID #	State City	Average U.S. City Cost	Anchorage AK Cost
28	ID Boise	$51.6/mi	$53.6/mi
41	Canada Winnipeg	$411/mi	$427/mi
56	MS Jackson	$302/mi	$314/mi
	AVERAGE VALUE =	$357/mile	$371/mile

COST INFLUENCING FACTORS

Numerous factors influence the cost of a vegetation control method. When cost data are gathered from outside sources, determining which factors have been considered in an estimate is difficult. For example, when a railroad hires a contractor to do track maintenance or vegetation control operations, a profit or markup on the cost of the work is paid. The same project when completed by internal labor forces includes no profit; thus the project may appear to be 10 to 15 percent less expensive assuming other factors are constant. Another item that is overlooked in economic evaluations is the cost of overhead and indirect for a project which, as stated in Chapter 5, can increase the total project cost 10 to 20 percent.

Productivity greatly influences the cost of a vegetation control operation and may vary because of a number of factors. As the amount of rail traffic along a particular line increases, the productivity of a vegetation control operation decreases because equipment must clear the track for other traffic to pass. Some operations, such as undercutting, require complete closure of the track for a specified period of time which may impede other rail traffic. As experienced for most construction projects, the efficiency is lowest at the beginning of the operation. Once the crew becomes familiar with the equipment and the process, the efficiency and productivity increases. A learning curve exists for each vegetation control operation while the crew becomes proficient at the specific task.

Mechanical problems also hinder efficiency of railroad operations. These mechanical failures are unpredictable and costly because much time may be spent in repair. Good maintenance can alleviate some of these problems, but unexpected situations probably will arise. With so many variables influencing the operation efficiency, establishing an accurate efficiency for an operation is difficult, and operation efficiencies are site specific for a particular time and location. Several different productivities in the independent cost analyses, Chapter 5, were considered for most operations in order to establish some of the cost deviations associated with productivity.

The cost of equipment may vary depending on the brand and the model of the product. The equipment cost is not a substantial portion of the total treatment cost for several of the vegetation control methods, but for brush cutting, using the ballast regulator, and undercutting the equipment cost is an important cost component. Maintenance and fuel costs are less obvious costs and likely to be neglected in a cost estimate. Usually these costs do not contribute a large percentage toward the total treatment cost, but for brush cutting, using the ballast regulator and undercutting they should not be ignored as the final treatment cost will be noticeably influenced.

The materials cost is a large portion of the treatment cost for methods such as undercutting, reballasting, and herbicide application. As stated in Chapter 5, the materials cost is influenced by a number of factors including the quality of materials purchased, the distance of materials transport, and the type of materials used. These factors also contribute to the cost herbicide application chemicals.

Figures 7, 8, and 9 graphically delineate the portion of the total treatment cost that each component comprises. These figures are based on 1991 dollar base, U.S. average city data from the independent cost estimate in Chapter 5.

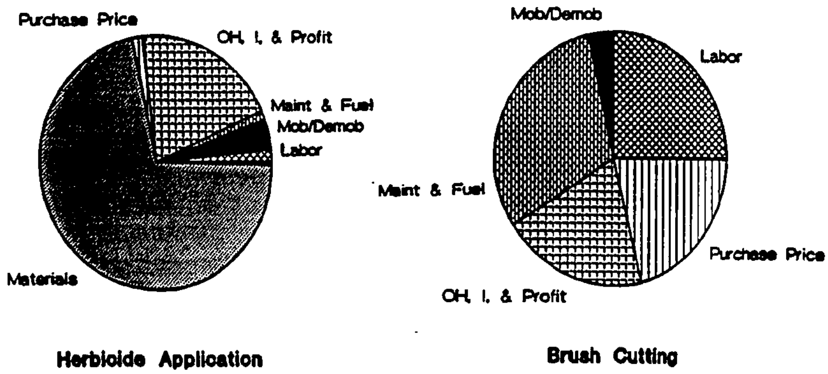


Figure 7: Cost Components for Herbicide Application and Brush Cutting. Average U.S. city data, 1991 dollar base.

The primary cost component for herbicide application is the materials cost. The independent estimate was based on a materials price for a small quantity of herbicide. If the product was purchased in bulk directly from the manufacturer, the chemical company, then the price would be substantially less, thus reducing the total cost for this alternative.

The cost of brush cutting, as shown in Figure 7, is composed of nearly equal portions of maintenance and fuel; labor; purchase price; and overhead, indirect and profit costs. Mobilization and demobilization contribute a minor portion of the total cost. If maintenance, fuel and the equipment purchase price are considered together, as they are all equipment costs, they contribute about half of the total treatment cost. A change in this cost component is likely to have a noticeable effect on the total treatment cost of brush cutting.

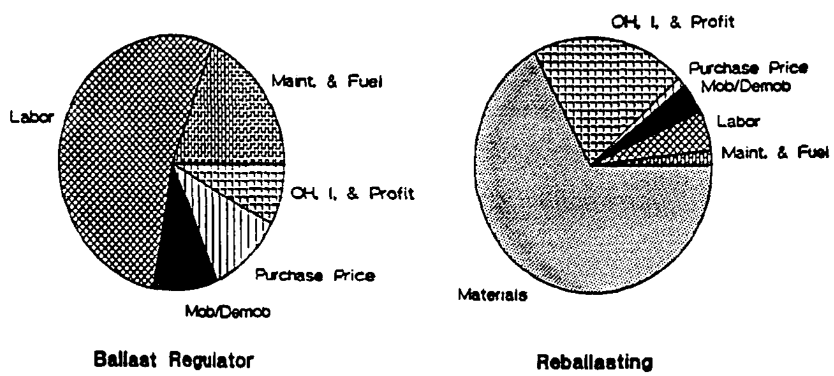


Figure 8: Cost Components for Using the Ballast Regulator and Reballasting. Average U.S. city data, 1991 dollar base.

Labor is a large portion of the cost of using a ballast regulator to control vegetation. Labor costs are usually fairly stable, but can fluctuate from region to region, making this operation more expensive in some areas than others.

The cost of reballasting is greatly influenced by the materials costs as this composes the majority of the treatment cost for the operation. If less expensive materials of acceptable quality are available, the cost for this alternative will be decreased substantially.

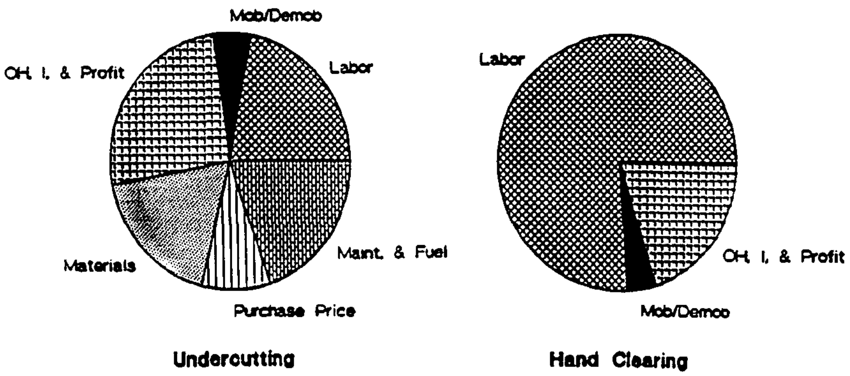


Figure 9: Cost Components for Undercutting and Hand Clearing. Average U.S. city data, 1991 dollar base.

Undercutting is divided almost equally between labor; maintenance and fuel; materials; and overhead, indirect and profit costs. Similar to the reballasting process, if materials costs are reduced, the total treatment cost would be impacted significantly. When the equipment purchase price, maintenance and fuel costs are considered together as equipment costs, they comprise the largest portion of the costs for undercutting. Fluctuations of these costs will noticeably influence the treatment cost for undercutting.

Figure 9 shows that hand clearing is a labor intensive process. If a minimum wage work force was provided, then the cost for this method could be substantially reduced and thus it would be a more attractive alternative. Free labor through a volunteer or convict work program would also greatly reduce the cost of this project. Additional insurance may be needed for this type of work force, but it would make this alternative one of the least expensive vegetation control options.

ADJUSTMENT FOR TREATMENT LIFE

Direct comparisons between the cost of treatment options are not valid unless the treatment life is considered. Each of the alternatives can be adjusted to reflect application frequency of the vegetation control method. The costs are adjusted to reflect the treatment life by dividing the treatment life by the cost per treatment. Table 63 demonstrates a sample calculation for brush cutting. A discussion of each of the vegetation control methods and the estimated treatment life follows.

Table 63: Sample Calculation of Treatment Life Adjustment. Average U.S. city data, 1991 dollar base.

Given:	Average Brush Cutting Cost Per Mile = $645
	Treatment Life = 2 Years
Find:	Cost Per Mile For Treatment Life
Calculation:	
($645/mile) * (1 treatment/2 years) = $323/mile yearly	

Herbicide Application

It is customary to apply chemicals for herbicide application every year to the right-of-way, as indicated by the survey responses in Chapter 4. Chemicals must be applied twice yearly in some areas because of the long growing season. For this discussion and analyses, a standard one year treatment life with one application per year is considered. From the data reported by the survey respondents, the average cost (average U.S. city data, 1991) was $188 per mile (Table 60) to apply herbicides for approximately a 16 to 24 foot application width. The cost computed in the independent estimate was $485 per mile for a 20 foot application width. The difference in the independent estimate costs and survey costs may caused by numerous factors, as discussed previously, such as varying chemical costs, the exclusion of profit, overhead and indirect costs in the survey costs, and varying application rates and productivities.

The cost reported in the literature (Brauer, 1983) is $25 to $125 per acre which is $79 to $392 per mile when converted to an average U.S. city data base in 1991 for a 20 foot width. Sheahan (1986) reports a herbicide application cost of $296 per mile (average U.S. city data, 1991 dollar base) for a 24 foot width. The range of values per mile for a 20 foot width is $79 to $392.

Brush Cutting

The frequency of brush cutting for railroads is dependent on the type and growth rates of vegetation present locally. Literature and the survey responses show that shrubs are commonly removed along the right-of-way every two or three years (Sheahan, 1986). The cost of this operation is strictly for vegetation control and has no other track maintenance benefits. The average cost (average U.S. city data, 1991 dollar base) per mile reported for brush cutting from the survey, as presented in Chapter 4, was $720 (shown in Table 61), and for the independent estimate was $1,850 per mile (for a 24 foot cut) and $1,470 per mile (for a 28 foot cut). The two brush cutting cost values from the independent estimate are based on different productivities. Sheahan (1988) reported a brush cutting cost (converted to average U.S. city data, 1991 dollar base) of $1,090 per mile for a 24 foot width.

For two and three year treatment lives the survey cost was $360 and $240 per mile, respectively. For a two year treatment life the independent estimate ranged from $735 to $925 per mile with an average of $830 per mile. When a three year treatment life was considered the brush cutting cost ranged from $490 to $617 per mile with an average of $554 per mile.

Ballast Regulator

The ballast regulator is commonly used for railroad track maintenance operations along the rail so part of the cost for this vegetation control operation can be borne by the track maintenance program. Using the ballast regulator to control vegetation may "waste" ballast by pushing good material outside of the roadbed area. This may not be important in areas where there is excess ballast, but in other locations the wasted ballast must be replaced and may result in increased maintenance costs. Careful use of the ballast regulator, by a skilled operator, so that the equipment scrapes away the vegetation without removing ballast is possible. Vegetation control of perennials is not as effective, using this method, as the root system is not disturbed.

Assuming that the ballast regulator is used on the entire track every four years, 25 percent of the track is treated annually (Preston, 1990). Therefore the vegetation control program would only have to expend 75 percent of the costs per year. For the purpose of this study a treatment life of one to two years is estimated for this method of vegetation control. This method is not one normally employed for vegetation control, thus specific data on the time period for vegetation regrowth is unavailable.

The cost (average U.S. city data, 1991 dollar base) per mile reported from the survey respondents was $357, and from the independent estimate was $880 per mile. When the cost shared by the track maintenance program is considered the costs are $268 from the survey data and $660 from the independent analyses. Considering a two year treatment life and 25 percent of the cost borne by the maintenance program, the survey cost and the independent estimate is $134 and $330 per mile, respectively.

Reballasting

Reballasting is another track maintenance operation that can be modified for vegetation control so some of the cost can be borne by the track maintenance program. If the entire track is reballasted in five year cycles, as estimated on the Alaska Railroad (Preston, 1990) and in the literature (Cataldi, 1981), then it can be considered that 20 percent of the total track is reballasted for maintenance procedures annually. This would result in the vegetation control program only bearing 80 percent of the cost of reballasting per year. There are some track maintenance benefits associated with reballasting for vegetation control such as increased track structure strength. These benefits will not be considered quantitatively, but will be discussed in later sections.

Treatment lives of three, five and seven years are assumed for this estimate. Similar to ballast regulator vegetation control, the process of reballasting for vegetation control is not common; thus specific data on vegetative regrowth is unavailable. A range of treatment life values was chosen to account for this uncertainty.

No cost data from the survey respondents were reported for reballasting. From the independent estimate the average cost per mile for reballasting (average U.S. city data, 1991 dollar base) was $8,710. For reballasting on three, five, and seven year cycles the cost per mile was $2,320, $1,390, and $992, respectively. Table 64 demonstrates a sample calculation.

Table 64: Sample Calculation of Reballasting Treatment Life Adjustment. Average U.S. city data, 1991 dollar base.

Given:	Yearly Reballasting Cost = $9,460/mile Treatment Life = 3 Years 80% of Cost is Borne by Vegetation Control
Find:	Reballasting Cost for 3 Year Treatment Life
Calculation: ($8,710/mile) * (80%) * (1 treatment/3 years) = $2,320/mile	

Undercutting

Undercutting is used in track maintenance as well as for vegetation control, and part of the cost for this operation can be shared by the track maintenance program. The track is undercut for track maintenance on a less frequent basis than reballasting, approximately every five to seven years. A five year value was chosen for this estimate. When the track is undercut every five years 20 percent of the track is undercut annually. Similar to reballasting, 80 percent of the cost of the undercutting operation is borne by the vegetation control program. Treatment lives of five and seven years are assumed with this operation. Specific data on vegetative regrowth were unavailable for undercutting so treatment life values of a longer duration than those used for the reballasting process were chosen because a deeper layer of ballast is added during undercutting.

No data for undercutting costs were given by the survey respondents. The calculated cost per mile from the independent estimate for metal slag ballast with a 20 percent recovery rate was $86,800. The cost per mile for granite with a 20 percent recovery rate was $114,000. Considering five and seven year treatment lives, the cost per mile ranged from $13,900 to $9,920 for metal slag and $18,200 to $13,000 for granite ballast.

Hand Clearing

Hand clearing is used strictly for vegetation control and has no track maintenance applications. The reported cost per mile (average U.S. city, 1991 dollar base) from the survey data was $2,490 and from the independent estimate the cost per mile was $4,470.

Treatment lives of one, two and three years were considered, and the amount of vegetation control gained by the hand clearing operation depends on the vegetative species present. When the two and three year treatment lives were considered, the costs from the survey were $2,490 and $1,245 per mile, respectively. The cost per mile for the independent estimate considering two and three year treatment lives was $2,240 and $1,490, respectively.

SUMMARY AND COMPARISON OF VEGETATION CONTROL METHODS

Table 65 contains a summary of the treatment lives considered and the cost per mile of the treatment methods for average U.S. data base and Anchorage, Alaska data base (for the independent analysis).

Table 65: Cost Summary of Vegetation Control Methods. 1991 dollar base.

Vegetation Control Method	Treatment Life (years)	Cost/Mile Survey Avg. U.S.	Independent Avg. U.S.	Independent Anch., AK
Herbicide	1	$188/mi	$485/mi	$636/mi
Brush Cutting	2	$360/mi	$830/mi	$1,090/mi
	3	$240/mi	$554/mi	$727/mi
Ballast Reg.	1	$268/mi	$660/mi	$866/mi
	2	$134/mi	$330/mi	$433/mi
Reballasting	3	*	$2,320/mi	$3,040/mi
	5	*	$1,390/mi	$1,390/mi
	7	*	$922/mi	$1,820/mi
Undercutting				
Metal Slag	5	*	$13,900/mi	$18,200/mi
(20% recovery)	7	*	$9,920/mi	$13,000/mi
Granite	5	*	$18,200/mi	$23,900/mi
(20% recovery)	7	*	$13,000/mi	$17,100/mi
Hand Clearing	1	$2,490/mi	$4,470/mi	$5,860/mi
	2	$1,250/mi	$2,240/mi	$2,940/mi
	3	$830/mi	$1,490/mi	$1,960/mi

* No data reported from the survey respondents for this method

The treatment methods were arranged in order of increasing cost on a per mile basis as shown in Figure 10. The treatment life chosen influenced the position of the alternative in the ranking scheme. For both the survey data and the independent cost estimate calculations, vegetation removal using the ballast regulator with a two year treatment life was the least expensive option. For the independent estimate the second least expensive option was herbicide application with a one year treatment life. The cost of herbicide application was within $155 per mile of the treatment cost for employing the ballast regulator. If herbicide application controls vegetation for two years then it would be less expensive than using ballast regulator with a two year treatment life. Purchasing chemicals on a wholesale basis, as mentioned previously, may reduce the herbicide treatment cost substantially and make it a less expensive vegetation control alternative than using the ballast regulator. For example if the herbicide application cost was reduced by 32 percent it would cost approximately the same as using the ballast regulator with a two year treatment life. Considering the survey data, brush cutting with treatment lives of three years and two years, were the second and third lowest cost alternatives.

For both the independent cost estimate and the survey data, the three lowest cost alternatives were herbicide application, using the ballast regulator, and brush cutting. Reballasting ranked next in the independent estimate followed by hand clearing. If volunteer or convict labor was used for hand clearing, as mentioned previously, then the cost would be reduced substantially. As shown in Figure 9, labor is the major cost component of this method of vegetation control. When a portion of that cost is removed, it becomes a much less expensive alternative. For example if the labor cost was reduced by two thirds through the use of a less expensive labor force, the cost per mile of hand clearing would be $1,480, which is more competitive with brush cutting and reballasting. Figures 10 and 11 graphically depict the ranking of the alternatives for both the survey data and the independent cost estimate for average U.S. data, 1991 dollar base. Figure 10 depicts the six alternatives with the lowest cost and Figure 11 depicts the next seven alternatives. Figure 12 illustrates the ranking of the five least expensive alternatives when a conservative approach is taken and the shortest treatment life is considered for each treatment method. Based on these conservative treatment lives the least expensive vegetation control alternative is herbicide use with a one year treatment life. Table 66 is a key to Figures 10, 11, and 12.

Table 66: Key of Abbreviations Used in Figures 10, 11, and 12.

Abbreviation	Vegetation Control Method	Treatment Life
Herb1	Herbicide Application	1 Year
BReg1	Ballast Regulator	1 Year
BReg2	Ballast Regulator	2 Years
BCut2	Brush Cutter	2 Years
BCut3	Brush Cutter	3 Years
Rebal3	Reballasting	3 Years
Rebal5	Reballasting	5 Years
Rebal7	Reballasting	7 Years
Han1	Hand Clearing	1 Year
Han2	Hand Clearing	2 Years
Han3	Hand Clearing	3 Years
Undr5	Undercutter	5 Years
Undr7	Undercutter	7 Years

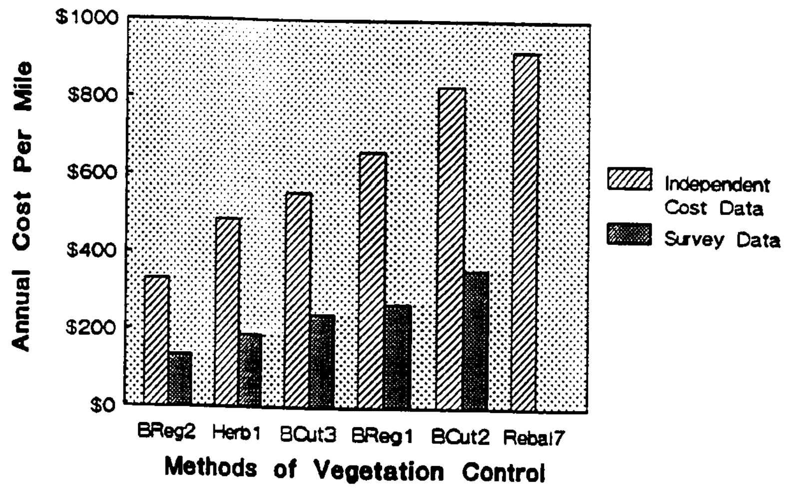


Figure 10: Ranking of Alternatives for Six Lowest Cost Vegetation Control Methods. Average U.S. city data, 1991 dollar base.

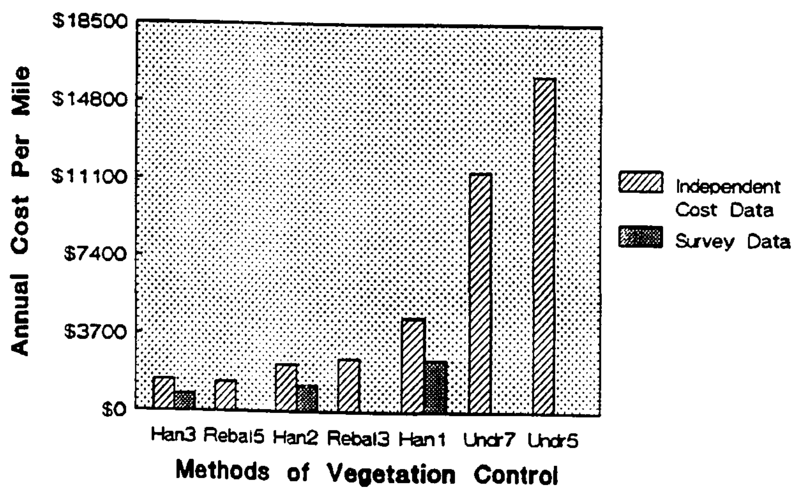


Figure 11: Ranking of the Next Seven Lowest Cost Alternatives for Vegetation Control. Average U.S. city data, 1991 dollar base.

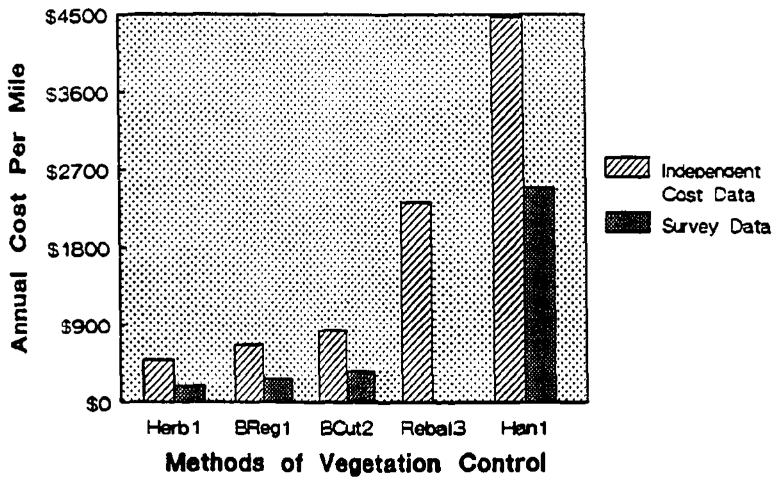


Figure 12: Ranking of Vegetation Control Alternatives Using Conservative Treatment Lives. Average U.S. city data, 1991 dollar base.

COMBINATIONS OF ALTERNATIVES

Part of the theory of integrated vegetation management is that all alternatives should be considered. This includes investigating several alternatives simultaneously. One alternative may be limited by either a physical or a regulatory restraint and thus lend itself to combination with another alternative for vegetation control. For example, some states have regulations that require a certain setback distance from water when herbicides are applied. For this operation there are areas of the rail not treated, and another form of vegetation control would be needed to complete the vegetation control program to eliminate vegetation in those areas. Public concern and resistance may also be an important influencing factor.

The practice of developing a combination of vegetation control techniques to eliminate unwanted vegetation is very site specific. Each railroad would have to look at its specific needs and determine which method or combination of methods gives the most economic vegetation control at the desired level of control. This lends itself to establishing a system-wide vegetation control program, as discussed in Chapter 3, that considers the level of treatment desired, the cost of each alternative, and the effectiveness of each control method on the undesired vegetation species present.

CHAPTER 7

SUMMARY AND CONCLUSIONS

Vegetation control by herbicide application, brush cutting, use of a ballast regulator, reballasting, undercutting, and hand clearing were examined for this study. A survey was distributed to 174 railroads (a list of the railroads is located in Appendix A) in order to develop a data base of vegetation control methods used on railroad rights-of-way. Information on vegetation control procedures as well as cost data were gathered from the survey, and data are presented in Chapter 4. An independent cost analysis, presented in Chapter 5, was developed to compare with the data obtained by the survey.

A summary of the vegetation control methods is presented in this chapter, and conclusions are reached based on the study.

SUMMARY

Vegetation control using integrated vegetation management techniques is not a new idea, but one that will gain more notoriety as time passes. Federal and state regulations, with their increased focus on chemical use, will likely cause railroads to review their existing vegetation control programs. Public pressure to reduce chemical usage may further influence railroads. Developing a management plan that utilizes several forms of vegetation control concurrently, will become more widespread with the increase of public pressure and regulatory control.

Most of the railroads responding to the survey, presented in Chapter 5, currently use more than one method to control unwanted vegetation on rights-of-way. Herbicide usage was reported by 93 percent of the railroads and mechanical vegetation control methods were used by 85 percent of the railroads. The period of complete reliance on herbicides as the solution to all vegetation control problems seems to be waning, leaving in its place an environment open to new methods and ideas.

Chapter 5 contains an economic analysis for a variety of vegetation control methods and a cost summary is included as Table 64 for vegetation control by herbicide application, brush cutting, using the ballast regulator, undercutting, and hand clearing. The economic analysis was based on a number of assumptions, which are discussed in detail in Chapter 5. A summary of the assumptions made are as follows in Table 67 Justification for these assumptions is discussed in Chapter 5.

Table 67: Summary of Assumptions

General Assumptions:
interest rate = 10%
mobilization & demobilization cost = 5%
overhead & indirect costs= 10%
profit costs = 15%
one shift per day equipment operation
Herbicide Application:
treatment (spray) width = 20 feet
chemical application rate = 65 gallons per acre
herbicide tank capacity = 2,000 gallons
dual treatment of the right-of-way was possible
productivity = 67 to 33 miles per day
equipment life = 10 years
annual equipment maintenance = 20% of the first cost
annual equipment operation = 200 shifts
one shift = 8 hours
Brush Cutting:
treatment width = 24 and 28 feet
annual equipment usage = 100 shifts
equipment life = ten years
productivity = 0.89 miles for a 24 foot width or 1.12 miles for a 28 foot width cut
one shift = 8 hours
Ballast Regulator:
treatment width = 10 feet
annual equipment usage = 200 shifts
equipment life = 14 years
annual maintenance = 20 percent of the first cost
productivity = 1,000 feet per hour
one shift = 5 hours
Reballasting:
treatment width = 10 feet
ballast placement = 3 inches on the track
ballast transport distance = 250 miles
equipment productivity = 1,000 feet per hour
one shift = five hours per shift
Undercutting:
total ballast placement on the track = 14 inches
annual equipment usage = 200 shifts
one shift = five hours
ballast transport distance = 250 miles
productivity = 2,000 feet per day
Hand Clearing:
treatment width = 24 feet
productivity = 30 to 100 feet per laborer per hour

CONCLUSIONS

The least expensive vegetation control alternative on a per mile basis was the use of a ballast regulator with a two year treatment life. The cost associated with this method was $330 per mile as determined by the independent analysis, and $134 per mile from the survey cost data (average U.S. city data, 1991 dollar base). This alternative is limited by the reach of the ballast regulator to approximately five feet on each side of the track centerline. Another limitation is the fact that large shrubs and trees within the ballast regulator's reach would have to be removed before vegetation control to prevent damage to the ballast regulator.

The vegetation control alternative, not including the ballast regulator, that was the most economical on a per mile basis was herbicide application with a one year treatment life. The cost associated with this alternative was $485 per mile, as determined by the independent estimate presented in Chapter 5, and $188 per mile reported from the survey data (average U.S. city data, 1991 dollar base). Some of the drawbacks of this method, as discussed previously, are the risk of contaminating a water supply or damaging crops through herbicide drift, herbicide leaching through the soil into the groundwater, and the impact on nontargeted vegetation and animals from herbicides spreading outside the application zone. Regulatory restrictions may be placed on herbicide application near a body of water which would reduce the number of track miles that herbicides can be applied.

The costs associated with herbicide application and ballast regulator vegetation control are within 32 percent of each other for the independent analysis and within 29 percent for the survey data. The smaller difference between the ballast regulator and herbicide application costs reported by the survey data is most likely because the herbicide application chemicals were purchased in bulk, thus less expensive. Figure 7 shows the dependence of the total herbicide application cost on the materials cost.

Each of these vegetation control methods, herbicide and ballast regulator use, have different positive and negative aspects associated with them, and they are complementary methods that can be combined to form an adequate and relatively inexpensive vegetation control program. One benefit of herbicide use is the application vehicle's ability to spray outside of the roadbed area past the ballast regulator's reach. Herbicide application may also control vegetative species, such as shrubs, that are difficult to remove with a ballast regulator. Herbicides also have the potential to control vegetation for more than one year, which would make them less expensive than using the ballast regulator.

Conversely, the ballast regulator can be used where there are sensitive corps, bodies of water, or other areas where herbicide drift would be detrimental. The ballast regulator, since it has track maintenance functions, can be used to remove vegetation in areas where there is excess ballast. Some vegetation species may not respond to the herbicide treatment, and the ballast regulator can be used as a cleanup tool to destroy vegetation that herbicide application is unable to eliminate. The ballast regulator may be used in areas where public concern about chemical usage is great which may enhance the railroad's public image because herbicides are not viewed as the sole form of vegetation control.

The next most economic vegetation control option was brush cutting with associated costs of $554 per mile for the independent estimate and $240 per mile for the survey data, based on a three year treatment life and average U.S. data in a 1991 dollar base. This vegetation control alternative can easily fit into vegetation control program with herbicides and the ballast regulator. A brush cutter is an excellent way to control vegetation that inhibits visibility outside of the roadbed area because, as discussed in Chapter 3, it leaves the beneficial low growing species intact. The brush cutter can also be used in the roadbed area to eliminate shrubs before ballast regulator vegetation control, or in areas where shrubs pose a special problem.

Each vegetation control method discussed in this thesis has a place in railroad vegetation control programs and should be considered. For example, as mentioned earlier, if there is a group of inexpensive or free labor, then hand clearing becomes an economic option and should be considered for use where feasible. Also, vegetation control programs should be coordinated with track maintenance operations when possible to gain the maximum vegetation control benefit from the maintenance procedure.

In conclusion, railroads should focus on vegetation control as a system and use IVM management techniques to develop a complete program that satisfies their needs, is economic, and takes advantage of all feasible vegetation control methods. Annual evaluations of the vegetation control program will make it flexible and able to grow and meet their needs as conditions change. This approach would improve the railroad's public image by a decreased dependance on chemical use, and also provide an economic and adequate vegetation control program. The prior planning may entail an initial time and money commitment, but in the future can prove to decrease their overall vegetation control budget leaving money for other needed railroad expenditures.

CHAPTER 8

RECOMENDATIONS FOR FURTHER STUDY

There are several areas in this study that could be enhanced by further work. This chapter contains a summary of some of these areas which include establishment of a better system of railroad record keeping that specifically addresses vegetation control costs, developing a field study program for treatment life and vegetation control effectiveness, and establishing the risks associated with different vegetation control methods.

A program of more complete record keeping on railroads should be developed to establish accurate data for different methods of vegetation control. Some of the items that should be included are equipment and maintenance costs along with work productivities of various vegetation control methods.

One of the areas where data is lacking for vegetation control evaluations is the treatment effectiveness of methods such as using a ballast regulator, undercutting, and reballasting. Establishing the frequency of treatment needed for adequate vegetation control will enable accurate cost evaluations that reflect field conditions to be developed. These field studies would be most effective if they were based on a number of growing seasons and represented different areas along the railroad.

Another aspect of vegetation control is the potential health and safety risks associated with each method of vegetation control. For example, the brush cutter poses a potential danger because of flying debris. Herbicide application may pose a threat if there is a large spill of chemicals in a sensitive area. In a future study, an analysis should be done to quantify these risks so the health and safety aspects of vegetation control can be included in the analysis.

In addition, this report should be circulated to the survey respondents for confirmation of information, assumptions, deviations, and new information. As new IVM techniques, steam as a means of vegetation control for example, or combinations of methods become available, they should be evaluated in a similar manner to this report. Finally, this information needs to be evaluated specifically for the ARRC, or other railroads who wish to use the information, to determine its relevancy and accuracy.

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APPENDIX A: RAILROAD SURVEY FORMS

Letter Sent To Railroads and Survey Form

Second Letter (Follow-up) Sent to Railroads and Survey Form

Environmental Quality Engineering

UNIVERSITY OF ALASKA FAIRBANKS

School of Engineering
306 Tanana Drive • Fairbanks, Alaska 99775-0660

March 15, 1989

Railroad
street
city , state zip

Dear Correspondent , title :

The University of Alaska Fairbanks has contracted with the Alaska Railroad Corporation to study degradation and migration of herbicides along the railbelt. A field testing program is in progress to examine two particular herbicides: Velpar (hexazinone) which is manufactured by Dupont Chemical and Garlon 3A (triclopyr) which is manufactured by DOW.

One aspect of this project involves determining alternative methods of vegetation control used on railroad right-of-way throughout the United States and Canada. We are interested in any Integrated Vegetation Management (IVM) techniques that you are employing for the purpose of track maintenance in the ballast and subgrade area. The focus of this research is to obtain cost and effectiveness information for comparing vegetation control methods.

Our IVM study may examine a number of methods including thermal, use of a ballast regulator, reballasting, use of a Jordan spreader, mechanical cutting (including hand clearing), salt, herbicides, combinations of the above, and perhaps others. Ultimately, we anticipate that the Alaska Railroad Corporation will use several of the alternatives and attempt to minimize the use of herbicides.

Please complete the attached questionnaire which will help us evaluate the effectiveness of different techniques to control vegetation. A summary brochure which describes the herbicide portion of this project is enclosed. Later, we will forward you a brochure on the IVM portion of the study.

Your cooperation and assistance will be greatly appreciated and should you desire additional information please call my research assistant, Ms. Jill Munson, at (907) 474-6129.

Sincerely, Tim Tilsworth

Timothy Tilsworth, Phd, P.E.
Professor of Environmental Quality
Engineering and Civil Engineering

Railroad Vegetation Management Survey

1. Name, Title, Address, and Telephone Number of person responding to this survey. Date of response.

2. Briefly describe your railroad's methodology for vegetation control in the ballast/subgrade area and in the wider right-of-way. Include a short history of how you chose these methods. Please specify the separate methods used for the ballast/subgrade area and wider right-of-way. Are there any construction techniques or maintenance procedures that are used for vegetation management in the ballast/subgrade area? In the right-of-way?

   A. Are herbicides used? If so, which ones, how are they applied, and at what application rates and times? Are they applied only to the track and ballast area or to the entire right-of-way? What is the cost to apply the herbicides per mile in the track area? Per mile in the right-of-way? Is the herbicide applied by an in house crew, an outside contractor, or a combination of both? If you regularly use an outside contractor would you please give us the name and address.

B. Are mechanical cutting methods used (including hand clearing) in the subgrade/ballast area? In the right-of-way? What is the cost for this method (specify ballast/subgrade or right-of-way) per mile? What type of equipment is used in the ballast/subgrade area and in the right-of-way?

C. Are thermal/burning methods used in the ballast/subgrade area? In the right-of-way? How effective is this method and what type of equipment is used in this method (specify ballast/subgrade or right-of-way)? What is the cost of thermal/burning methods per mile in the ballast/subgrade area? In the right-of-way?

D. What other methods do you use? Please include the type of equipment used and costs for both ballast/subgrade and right-of-way maintenance.

3. Do you have reports describing or evaluating your vegetation management process? If so could you provide us a copy?

4. Have you conducted research on vegetation management? If so would you please provide any documentation that you have.

5. Do you have cost information documenting the cost effectiveness of your methods? If so would you please provide us a copy of the data and describe how it was collected (Eg. field observation, outside consultant, etc.).

6. If you are aware of studies or materials of interest to us would you please direct us to such.

7. Would you be willing to have someone from our study visit your operation to observe your IVM program? What time of year would be best to see the operations and to discuss your approach?

Please return this form to:
Ms. Jill Munson
361 Duckering Building
Civil Engineering Department
University of Alaska Fairbanks
Fairbanks, Alaska 99775

Environmental Quality Engineering

University of Alaska Fairbanks
School of Engineering
306 Tanana Drive
Fairbanks, Alaska 99775-0660

July 10, 1989

«Railroad»
«street»
«city», «state» «zip»

Dear «Correspondent»:

In May the University of Alaska Fairbanks mailed you a survey form requesting information on your railroad's vegetation management techniques. We have received about 40 responses to our survey and we are encouraged by them. However, your response was not among them.

We realize that the form was perhaps too complex and required too much time to complete. Your participation and information is very important to us! We have enclosed a shortened version of our survey and our primary interest is indicated in the attached questions.

We want to thank you for your assistance with this request. This is an important study, not only to us but to you as well, and we hope to share the results when it is completed.

Sincerely,

Tim Tilsworth

Timothy Tilsworth, Ph.D, P.E.
Professor of Environmental
Quality Engineering and
Civil Engineering

Integrated Vegetation Management Survey

1. Please attach a business card or print your name, address, railroad, and telephone number.

2. Are you presently or have you previously used herbicides to control vegetation in the right-of-way? (yes/no)__________
Which herbicides?____________________________________

3. Do you use any other alternative methods to control vegetation in the right-of-way? (yes/no) Please describe the type of equipment.

mechanical____

thermal____

ballast regulator____________________________________

others____

4. Would you be willing to answer future correspondence if we contacted you again? ________________________________

Thank you again for participating in this study.
Please use the self addressed envelope or return the survey form to:

Jill Chouinard, Research Assistant
361 Duckering Building
University of Alaska
Fairbanks, Alaska 99775

APPENDIX B: RAILROADS SURVEYED

Railroads Receiving Survey

Foreign Railroads (Excluding Canada) Receiving Survey

Railroads Responding To Survey

RAILROADS CONTACTED FOR THE SURVEY

Aberdeen, Carolina & Western RY. Co.
The Akron & Barberton Belt R.R. Co.
Alabama & Florida R.R.
Algoma Central Ry.
Alleghney R.R. Co.
The Alton & Southern RY. Co.
AMTRAK
The Apache Railway Co.
Apalachicola Northern R.R. Co.
Arkansas & Louisiana Missouri Railway Co.
Arkansas and Missouri R.R. Co.
AT & L Railroad Co.
The Atchison, Topeka & Santa Fe Railway Co.
Atlanta & Saint Andrews Bay Railway Co.
Austin R.R. Co., Inc.
Bangor and Aroostook Railroad Co.
Bay Colony Railroad Corp.
BC Rail LTD.
The Belt Railway Company of Chicago
Bessemer and Lake Erie Railroad Co.
Birmingham Southern Railroad Co.
British Columbia Hydro & Power Authority
Burlington Northern (Manitoba) LTD.
Burlington Northern Railroad Company
Cadillac & Lake City Railway Company
Camas Prairie Railroad Company
Cambria and Indiana Railroad Company
Canadian National Railways
Canadian Pacific LTD.
Cartier Railway Company
Cedar Rapids & Iowa City Railway Company
Cedar Valley Railroad Company
Central California Traction Company
Central Montana Rail,Inc.
Central Vermont Railway, Inc.
Chehalis Western Railroad
Chicago & Illinois Midland Railway Company
Chicago and North Western Railway Company
Chicago and Western Indiana Railroad Company
Chicago,Central & Pacific Railroad Company
Chicago, Missouri & Western Railway Company
Chicago South Shore & South Bend Railroad
Colorado & Wyoming Railway Company
Columbus and Greenville Railway Company
Consolidated Rail Corporation
Cooper Basin Railway, Inc.
CSX Transportation, Inc.
D & I Railroad Company
Dakota, Minnesota & Eastern Railroad Corporation

Dakota Southern Railway Company
Delaware Ostego Corporation
Denver & Rio Grande Western Railroad Company
Detroit & Mackinac Railway Company
Devco Railway
Duluth, Missabe and Iron Range Railway Company
Duluth, Winnipeg & Pacific Railway
East Camden & Highland Railroad Company
Eastern Shore Railroad, Inc.
Elgin, Joliet and Eastern Railway Company
Escanaba & Lake Superior Railroad Company
The Essex Terminal Railway Company
Eureka Southern Railroad Company, Inc.
Farmrail Corporation
Florida Central Railroad Company, Inc.
Florida East Coast Railway Company
Fordyce & Princeton Railroad Company
Grainbelt Corporation
Grand Trunk Western Railroad Company
The Great Western Railway Company
Greater Winnipeg Water District Railway
Green Bay & Western Railroad Company
Green Mountain Railroad Corporation
Guilford Transportation Industries, Inc.-Rail Division
Hillsdale County Railway Company, Inc.
Houston Belt & Terminal Railroad Compan
Huron and Eastern Railway Company, Inc.
Illinois Central Railroad Company
The Indiana & Ohio Rail Corporation
Indiana Harbor Belt Railroad Company
The Indiana Railroad Company
Indianapolis Union
Iowa Interstate Railroad, LTD.
Iowa Northern Railroad Company
Kankakee,Beaverville and Southern
The Kansas City Southern Railway Company
Kansas City Terminal Railway Company
Keokuk Junction Railway
Kiamichi Railroad Company, Inc.
Knox & Kane Railroad Company
K.W.T. Railway, Inc.
Kyle Railroad Company
Lake Superior & Ishpeming Railroad Company
The Lakefront Dock & Railroad Terminal Company
Lamoille Valley Railroad Company
The Logansport & Eel River Railroad Museum, Inc.
Los Angeles Junction Railway Company
Louisiana & Arkansas Railway Company
Louisiana & Delta Rail
The Louisiana & North West Rail Company
Maryland & Delaware Rail Company

Maryland Midland Railway, Inc.
McCloud River Rail Company
Meridian & Bigbee Rail Company
Mid-Michigan Rail, Inc.
Midsouth Corporation
The Minnesota Commercial Railway Company
Minnesota Valley Transportation Company Inc.-Southwest
Missippi Delta Rail
Mississippi Export Rail Company
Missouri-Kansas-Texas Rail Company
The Monogahela Railway Company
Montana Rail Link, Inc.
Montana Western Railway Company, Inc.
Nashville and Eastern Rail Corporation
Natchez Trace Rail
Nevada Northern Railway Co. c/o Los Angeles Dept. of Water & Power
New England Southern Rail Company, Inc.
New Orleans Public Belt Rail
New York & Lake Erie Rail
Norfolk Southern Corporation
Northwestern Pacific Rail Company
Octoraro Railway, Inc.
The Ogden Union Railway and Depot Company
Ontario Midland Rail Corporation
Ontario Northland Railway
Oregon & NOrthwestern Rail Company
Oregon,California & Eastern Railway Company
Paducah & Louisville Railway, Inc.
Patapsco & Black Rivers Rail Company
Pend Oreille Valley Rail
Peoria and Pekin Union Railway
Philadelphia, Bethlehem and New England Rail Company
The Pittsburg & Shawmut Rail Company
Pocono Northeast Railway, Inc.
Ponce & Guayama Railway
Port of Tillamook Bay Rail
Port Terminal Rail Association
Providence and Worcester Rail Company
Quebec North Shore & Labrador Railway Company
Rarus Railway Company
Red River Valley & Western Rail Company
Richmond, Fredericksburg & Potomac Rail Company
The Roberval and Saguenay Railway Company
Rochester & Southern Rail, Inc.
San Diego & Imperial Valley Rail Company
Shore Fast Line, Inc.
Soo Line Rail Company
South Buffalo Railway Company
South Central Tennessee Rail Company, Inc.
Southern Pacific Transportation Company

St. Louis Southwestern Railway Company
St. Maries River Rail Company
Tennken Rail Company, Inc.
Terminal Railway Alabama State Docks
Terminal Rail Association of St. Louis
The Texas Mexican Railway Company
Tidewater Southern Railway Company
Tradewater Railway Company
Trona Railway Company
Tuscola & Saginaw Railway Company, Inc.
Union Pacific Rail
Union Rail Company
Vermont Railway, Inc.
Via Rail Canada, Inc.
Washington Central Rail Company
The White Pass and Yukon Corporation LTD.
Winchester and Western Rail Company
Winchester and Western Rail Company
Winston-Salem Southbound Railway Company
Wisconsin & Calumet Rail Company, Inc.
Wisconsin & Southern Rail Company
Wisconsin Central LTD.
Youngstown & Southern Railway Company
Finnish State Railways (VR)

FOREIGN RAILWAYS (EXCLUDING CANADA) CONTACTED FOR SURVEY

Australian National Railways Commission
1 Richmond Road
Keswick, S.A. 5035
Australia
Atten: John C.B. Adams, Ch. Civil Engineer

Brazialian Federal Railways (RFFSA)
Rede Ferroviaria Federal S.A.
Rio de Janeiro, Brazil
Atten: Geraldo Figueiredo De Castro, Asst. Ch. Safety Info.

China Railway Foreign Service Corporation
PO Box 2495 10 Fuxing Rd.
8644215
Peoples Republic of China
Atten: Ma Yun-Lin, Head of Trans. Dept.

Danish State Railways (DSB)
Danske Statsbaner
Solvgade 40
DK 1349 Copenhagen K Denmark
Atten: Peter Langager, Dir. Gen.

French National Railways
Societe National des Chemins de Fer Francais
88 Rue St. Lazare
75436 Paris Cedex 9
France
Atten: Francais Taillanter, Dir. Trans.

German State Railway (DR)
Deutsche Reichsbahn
Voss Str. 33
DDR 1086 Berlin
German Democratic Republic
Atten: Peter-Goetz Kienast, Ch. Op & Traf. Mgr.

(West) German Federal Railway (DB)
Deutsche Bundesbahn
323 Geary St.
Union Square Su. 501

San Francisco, CA 94102
Atten: Annelises Lass-Roth, Area Sales Mgr.

British Railways Board (BRB)
P.O. Box 100 Euston Square
London, NW1 2DZ
Great Britian
Atten: M.C. Purbrick, Dir. Civil Eng.

National Railways of Mexico
Pacific Region
6 Apartado Postal 15-M
Guadalajara, Jal. 44100
Mexico
Atten: Ernesto Gutierrez, Asst. Supt. M.W. & Struct.

National Railways of Mexico (FNDEM)
Av. Central No. 140 Pisco 13
D.F. Mexico
Mexico
Atten: Gonzalo Gomez dela Mata, Mgr. M.W.

RESPONDENTS TO RAILROAD SURVEY

The Akron & Barberton Belt R.R. Co.
Alabama & Florida R.R.
Algoma Central Ry.
Alleghney R.R. Co.
The Alton & Southern RY. Co.
AMTRAK
The Apache Railway Co.
Apalachicola Northern R.R. Co.
Arkansas and Missouri R.R. Co.
The Atchison, Topeka & Santa Fe Railway Co.
Atlanta & Saint Andrews Bay Railway Co.
Austin R.R. Co., Inc.
Bangor and Aroostook Railroad Co.
BC Rail LTD.
Bessemer and Lake Erie Railroad Co.
Birmingham Southern Railroad Co.
British Columbia Hydro & Power Authority
Burlington Northern Railroad Company
Cadillac & Lake City Railway Company
Camas Prairie Railroad Company
Cambria and Indiana Railroad Company
Canadian National Railways
Canadian Pacific LTD.
Cartier Railway Company
Cedar Valley Railroad Company
Central Montana Rail,Inc.
Chicago and Western Indiana Railroad Company
Chicago South Shore & South Bend Railroad
Consolidated Rail Corporation
CSX Transportation, Inc.
Dakota Southern Railway Company
Delaware Ostego Corporation
Detroit & Mackinac Railway Company
Devco Railway
Duluth, Missabe and Iron Range Railway Company
East Camden & Highland Railroad Company
Elgin, Joliet and Eastern Railway Company
Escanaba & Lake Superior Railroad Company
The Essex Terminal Railway Company
Florida East Coast Railway Company
Greater Winnipeg Water District Railway
Green Bay & Western Railroad Company
Huron and Eastern Railway Company, Inc.
Illinois Central Railroad Company
The Indiana & Ohio Rail Corporation
The Indiana Railroad Company
Indianapolis Union
Kankakee,Beaverville and Southern

Keokuk Junction Railway
K.W.T. Railway, Inc.
Kyle Railroad Company
Louisiana & Delta Rail
Maryland Midland Railway, Inc.
McCloud River Rail Company
Mid-Michigan Rail, Inc.
Midsouth Corporation
The Minnesota Commercial Railway Company
Missippi Delta Rail
Mississippi Export Rail Company
Montana Western Railway Company, Inc.
Natchez Trace Rail
Nevada Northern Railway Co. c/o Los Angeles Dept. of Water & Power
New Orleans Public Belt Rail
Norfolk Southern Corporation
Northwestern Pacific Rail Company
Ontario Midland Rail Corporation
Ontario Northland Railway
Oregon,California & Eastern Railway Company
Paducah & Louisville Railway, Inc.
Patapsco & Black Rivers Rail Company
Pend Oreille Valley Rail
Peoria and Pekin Union Railway
Philadelphia, Bethlehem and New England Rail Company
The Pittsburg & Shawmut Rail Company
Port of Tillamook Bay Rail
Providence and Worcester Rail Company
Quebec North Shore & Labrador Railway Company
Rarus Railway Company
Red River Valley & Western Rail Company
Richmond, Fredericksburg & Potomac Rail Company
Rochester & Southern Rail, Inc.
San Diego & Imperial Valley Rail Company
Shore Fast Line, Inc.
South Buffalo Railway Company
South Central Tennessee Rail Company, Inc.
Southern Pacific Transportation Company
St. Maries River Rail Company
Terminal Railway Alabama State Docks
Terminal Rail Association of St. Louis
Tradewater Railway Company
Trona Railway Company
Tuscola & Saginaw Railway Company, Inc.
Union Pacific Rail
Union Rail Company
Vermont Railway, Inc.
Via Rail Canada, Inc.
Washington Central Rail Company
Winchester and Western Rail Company

Winston-Salem Southbound Railway Company
Wisconsin & Calumet Rail Company, Inc.
Wisconsin & Southern Rail Company
Wisconsin Central LTD.
Australian National Railway
Finnish State Railways (VR)
French National Railways

APPENDIX C: SUMMARY OF RAILROAD SURVEY RESPONSES

RAILROAD SURVEY RESPONSES

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
1	TX	Arsenal			no	brush cutter ballast regulator	no
2	FL	Garlon 3A Roundup Daconate 6 2,4-D amine Karmex Chlorate			no	tractor w/brush hog hand-held weed trimmer	no
3	AZ	Karmex Roundup Oust Atratol Garlon Arsenal Weed Blast Sprakil			no	mower brush cutter Jordan spreader	no
10	Canada	Tordon Krovar Glean			yes	on-track brush cutter ballast regulator	no
9	PA	Karmex-Oust Arsenal Roundup			no	high rail brush cutter chain saw	no
8	IL	Karmex 2,4-D amine Velpar Banvel		32 ft	no	tractor with mower chain saw	no
7	PA	Atratol Arsenal			no	weed eater trimlifts chippers	no
6	AZ	Hyvar XL			no	ballast regulator bladeing	no
5	FL	Roundup Karmex Oust Garlon 4 Diquat Hychlor	$75-100/mi		no	Kershaw brush cutter	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
4	AI	Rounoup 2,4-D Diquat Karmex Arsenal Garlon 4			no	RMC brush cutter brush hog ballast regulator	no
12	OH	Roundup Oust Arsenal			no	brush hog weed eater	
13	ME	yes (confidential)			yes	brush cutter ballast regulator	no
14	Canada	Spike Hyvar X Krovar I Roundup Glean Tordon 101 & 22K 2,4-D Banvel Primatol A80 Sodium TCA Fromox 80 WP	$360/mi $360/mi $354/mi	20 ft	no	weed wacker hand clearing @ 8 mandays/mi brush cutter @ $200/mi	
15	PA	Karmex Oust Weeder	$120/mi $88/mi	32 ft 26 ft	no	hand held power tools clear & grub w/excav. equipment	hand tools
16	Canada	Glyphosate Chlorsulfuron Diuron Simazine Fonasomine Spike			no	mower surfacer tamper reballasting	
101	AL	Diuron 4L Arsenal Roundup			no	Mechanical and manual brush cutting	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
17	KS	Tordon Garlon 2,4-D Atrizine Weed Master Banvil Arsenal Bush Master			no	undercutter brush cutter (shredder)	
29	CO	yes (unknown name)			no	no	no
28	ID	Oust Tordon 2,4-D	$58.85/mi $53.60/mi	32 ft 32 ft	no	ballast regulator Bantam shovel hand clearing	(cost $47/mi)
27	PA	yes					
26	Canada	Hyvar X & XL Karmex Krovar Velpar Glean Spike, 80W & 5G Primatol, 80 W & liquid Dycleer, 24 & liquid Krenite Tordon, 22K, 10K, & 101 Herbec 20P Calmix, Atra-Pell			yes	chain saw brush saw brush cutter	no
25	Canada	yes (unspecified)			steam	mower brushcutter	Borax competing vegetation techniques
24	Canada	Desormone Dycleer	$100,000/90 mi of track		no	hand clearing @ $1000/acre	
23	IA	Roundup			no	no	no
22	MT	Hi-Dep Banvel Tordon Roundup			no	ballast regulator	no
21	IL	yes (unknown)			no	no	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
20	IN	Roundup 2,4-D Garlon Arsenal	$130/mi		no	Pettibone brush cutter @ $200/mi bulldozer	no
19	PA	Karmex Atratol 90 Arsenac Oust Spike Weedar 64A Round-up Banval Tordon, K & 101 Velpar Garlon 3A Formula 40 Rodeo			no	brush cutter ballast regulator	no
18	FL	Roundup Oust 2,4-D Escort Arsenal Karmex Garlon Sprakill RWG - B4j	$200-250/mi	24 ft	no	cutting @ ~$1000/mi manual cutting @~$1500-2500/mi ballast regulator tamper undercutter spreader ditcher	has cost information article
30	SD	Landmaster II			no	rotary mower	
31	NY	2,4-D Roundup Garlon 3A RWC B-2 D-2			no	brush cutter ballast regulator	no
32	MI	Oust Karmex Surfel			no	Kershaw or RMC brush cutter	
33	Canada	no			no	ballast regulator speed swing machine	no
34	MN	Atratol 90 Oust 2,4-D amine Tordon 101 Banvel			yes	mechanical cutting hand cutting	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
38	AR	Arsenal Tordon K MSMA Diuron			no	weed eater	
37	IL	Oust Karmex Garlon 4	$7.80	36 ft	no	no	
36	MI	Roundup			no	on track brush cutter	govern. funded youth corps w/ hand tools
35	Canada	Karmex Duiron Aprazine			no	tractor weed cutter	
40	Finland	Gordoprin	$4.50 US/mi		no	coppice cutting machines	no
39	FL	yes			no	tractor/mower track mounted brush hog	no
41	Canada	Hyvar X-L Glean	$400Can/mi	32 ft	no	ballast regulator on track crane off track excavator	@ $400Can/mi @ $400Can/mi @ $1600Can/mi
42	WI	Karmex Atratol 90 Garlon 3A Tordon 101			no	Pettibone brush cutter brush saws	
43	MI	Oust Karmex Kalo Bio-88			no	ballast regulator	no
44	IL	Arsenal Roundup Oust 2,4-D			no	brush cutter tractor mower	no
102	IN	Arsenal Karmex 2,4-D			no	brush cutter ballast regulator off-track brush cutter	
45	OH	yes (unknown)			no	brush cutter hand clearing	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
46	PA	Karmex Atratol 90 Arsenac Oust Spike Weedar 64A Roundup Banvel Tordonk Tordon 101 Garlon 3A Formula 40 Rodeo Velpar			no	brush cutter ballast regulator	no
50	IL	Oust Roundup Spike ACME-Super brush killer Hyvar			no	no	no
49	IA	yes (unknown)	$8600/30 mi	32 ft	yes	rail mounted sickle mower chain saw	no
48	TN	Dacanate Karmex 2,4-D amine			no	ballast regulator brush hog	
47	KS	Oust Kravar 2,4-D amine Roundup Banvel			no	mower ballast regulator Jordan spreader	
51	LA	Arsenal			no	tractor & brush hog	
59	MD	Karmex Oust			no	brush cutter ballast regulator chain saw	no
58	CA	no			no	966 loader ballast regulator	no
57	MI	Velpar Oust 2-wD (?)			no	chain saw weed mower (brush hog) gas powered trimmer	no

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
56	MS	Roundup Oust	$70/acre	40 ft		Jordan ditcher @ $100/acre Kershaw brush cutter @ $90/acre	
		Arsenal Atrazine	$69/acre	24 ft			
		Arsenal Triclopyr	$60/acre	48 ft			
55	MN	no			no	weed mower ballast regulator	hand cut weeds hand pull weeds
54	MS	Arsenal Roundup Honcho			no	Jordan spreader	
53	MS	Roundup Oust 2,4-D		30 ft	no	no	hand clearing
52	MO	2,4-D Tordon Arsenal - WP granular LI 700			no	ballast regulator w/ broom	
60	MS	Arsenal 2,4-D Roundup Baconate Duron Karmex Krovar			no	Kershaw brush cutter Chain saw	hand tools
61	CA	no			no	hand held weed eater	no
62	LA	Krovar Karmex Oust 2,4-D amine Roundup Garlon 3A Spike 80W	$85/acre	13 to 24 ft	yes (past)		hand cut ($ 2X's, 10 X's time)
63	VA	list was not attached	~$100/mi	24 ft	yes	on-track brush cutter	no
64	CA	########	data unavailable				

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
67	NY	Roundup			no	brush hog chain saw weed whacker	no
66	Canada	##########	data unavailable				
65	OR	Krovar Tranizol Brush buster Weed done			yes	no	no
68	KY	Arsenal			no	Porter brush cutter	no
69	PA	yes			no	no	no
70	WA	Karmex Atroal 2,4-D Spike			no	brush cutter ballast regulator	no
71	IL	Karmex Oust Garlon 3A Tordon K Riverdale butyl ester 6D			no	no	no
72	PA	yes			no	no	no
73	PA	Diuron Arsenal Atratal		24 ft	no	bulldozer	no
74	OR	Roundup Cross Bow			no	brush cutter ditcher	no
75	RI	Roundup			no	brush cutter ballast regulator backhoe w/ rear mounted mowing attachment	no
76	Canada	Tordon 101			no	brush cutter	

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
80	MT	Tordon 22K R-11 2,4-D			no	no	
79	MN	Atrotol 2,4-D Karmex			no	no	no
78	VA	Velpar Arsenal 2,4-D Oust Kareex			yes	bush hog	
77	NY	Karmex Oust 2,4-D Weedar 64 Formula 40		24 ft	no	hand or power equip. @ $420/mi chain saw	
81	CA	no			no	yes - unspecified	no
82	NJ	Kareex Atratol 90 Weedar 64 (2,4-D) Arsenal			no	no	no
83	PA	yes			no	no	no
84	TN	Oust Roundout (?) 2,4-D Arsenal pramital Habco hychlor			no	chain saw brush axe ballast regulator	no
85	CA	yes (contractor applied)			no	plowing grading	geotextiles hand removal
86	ID	Atratol Oust Tordon 22K Krovar 2,4-D			no	no	

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
91	AL	Arsenal Induce-F			no	brush hog	no
90	IL	yes contractor selects			no	brush cutter on speedswing tractor w/ sickle bar brush hog	no
89	KY	Arsenal			no	no	
88	CA	no			no	ballast regulator	
87	MI	yes (contractor)			no	brush axe chain saw ballast regulator	prisoners
103	PA	Karmex Oust Weeder	main - $102/mi yard - $88/mi	16 ft 13 ft	no	no	no
92	NE	Karmex 2,4-D Tordon 101 Banvel Garlon Oust Telar Roundup	$72.50 - 75/	24 ft	yes	mech. cutting @ $1750/mi+ brush hog mower grader ballast regulator	no weed burner @ $1000/mi
93	PA	Karmex Oust Weeder	@ $102/mi	32 ft	no	mechanical cutter hand held power tools excavating equipment	hand tools
		same as above	@ $88/mi	26 ft			
94	VT	Karmex Oust Rodeo Arsenal Spike 2,4-D Banvel			no	high rail brush cutter mower chain saw brush master ballast regulator	
104	Canada	no			no	hand operated mech. cutting	

ID #	Location	Herbicides	Cost	Width	Thermal	Mechanical	Others
99	WA	Arsenal Divron	@ $150-200/m	32 ft	no	backhoe mounted brush blade	
98	VA	yes (contractor)			no	chain saw back hoe weed eater ballast regulator	no
97	WI	Cyanimid Arsenal 2,4-D Roundup Oust			no	brush cutter ballast regulator	no
96	WI	Oust 88 2,4-D amine Tordon 101 Garlon 4		28 ft	no	Canron brush cutter @ $0.20/mi	convicts, hand labor
95	WI	Atratol Karmex 2,4-D	@ $61.4/mi				
		Tordon 101 Garlon 3	@ $172.88/mi	32 ft	no	brush cutter @ $250/mi	